

General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.
- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.
- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.
- This document is paginated as submitted by the original source.
- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

MANNED REMOTE WORK STATION DEVELOPMENT ARTICLE

(NASA-CR-151871) MANNED REMOTE WORK STATION
DEVELOPMENT ARTICLE Interim Review No. 2
(Grumman Aerospace Corp.) 260 p
HC A12/MF A01

CSCI 22B

G3/16

N79-16057

Unclas
43388

SECOND ITERIM REVIEW

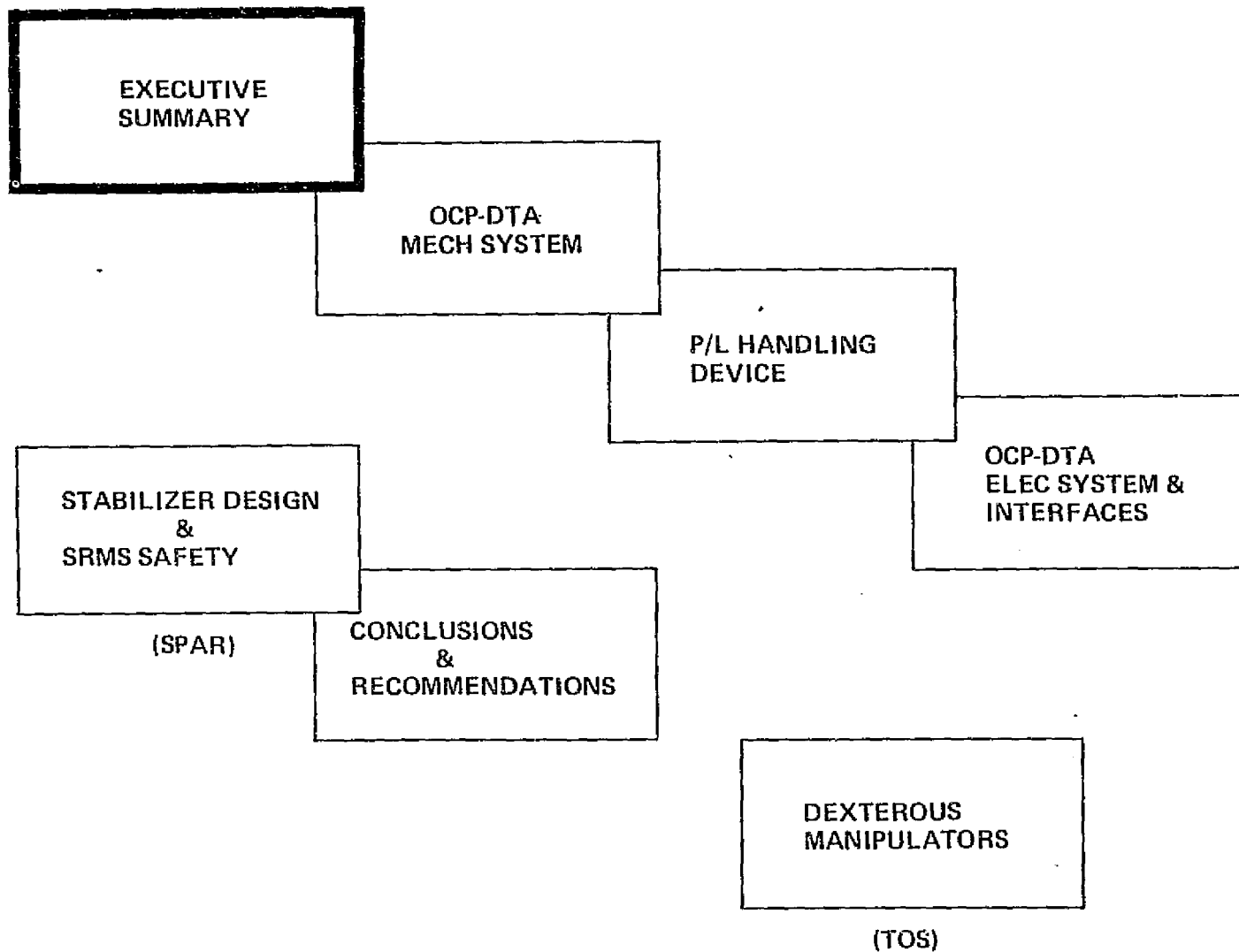
Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TEXAS 77058

By
GRUMMAN AEROSPACE CORPORATION
BETHPAGE, N.Y. 11714

Report NSS-MR RP 011

8 November 1978





PROGRAM OBJECTIVES

The two prime objectives for the Manned Remote Work Station (MRWS) Development Article study (NAS9-15507) are to first evaluate the MRWS flight article roles and associated design concepts for fundamental requirements and embody key technology developments into a simulation program. The second objective is to provide detail manufacturing drawings and schedules for a simulator development test article.

The approach outlined on the opposite page, establishes flight article requirements based on past studies of Solar Power Satellite, orbital construction support equipments, construction bases and near-term Shuttle operations.

In the process of studying flight article requirements, simulation objectives were established for those technology issues that can best be addressed on a simulator. Concepts for full-scale and sub-scale simulators were then studied to establish an overall approach to studying MRWS requirements. Emphasis then shifted to design and specification of a full-scale development test article to be used in the JSC Manipulator Development Facility.

PROGRAM OBJECTIVES

- (1) ANALYZE AND DESIGN MRWS THAT CAN OPERATE FROM END OF LARGE CRANE & OTHER MULTI-ROLE FUNCTIONS**
- (2) DEVELOP DESIGN, SPECIFICATIONS, DRAWING, MFG REQMTS, COST & SCHEDULE FOR MRWS SIMULATOR.**

APPROACH

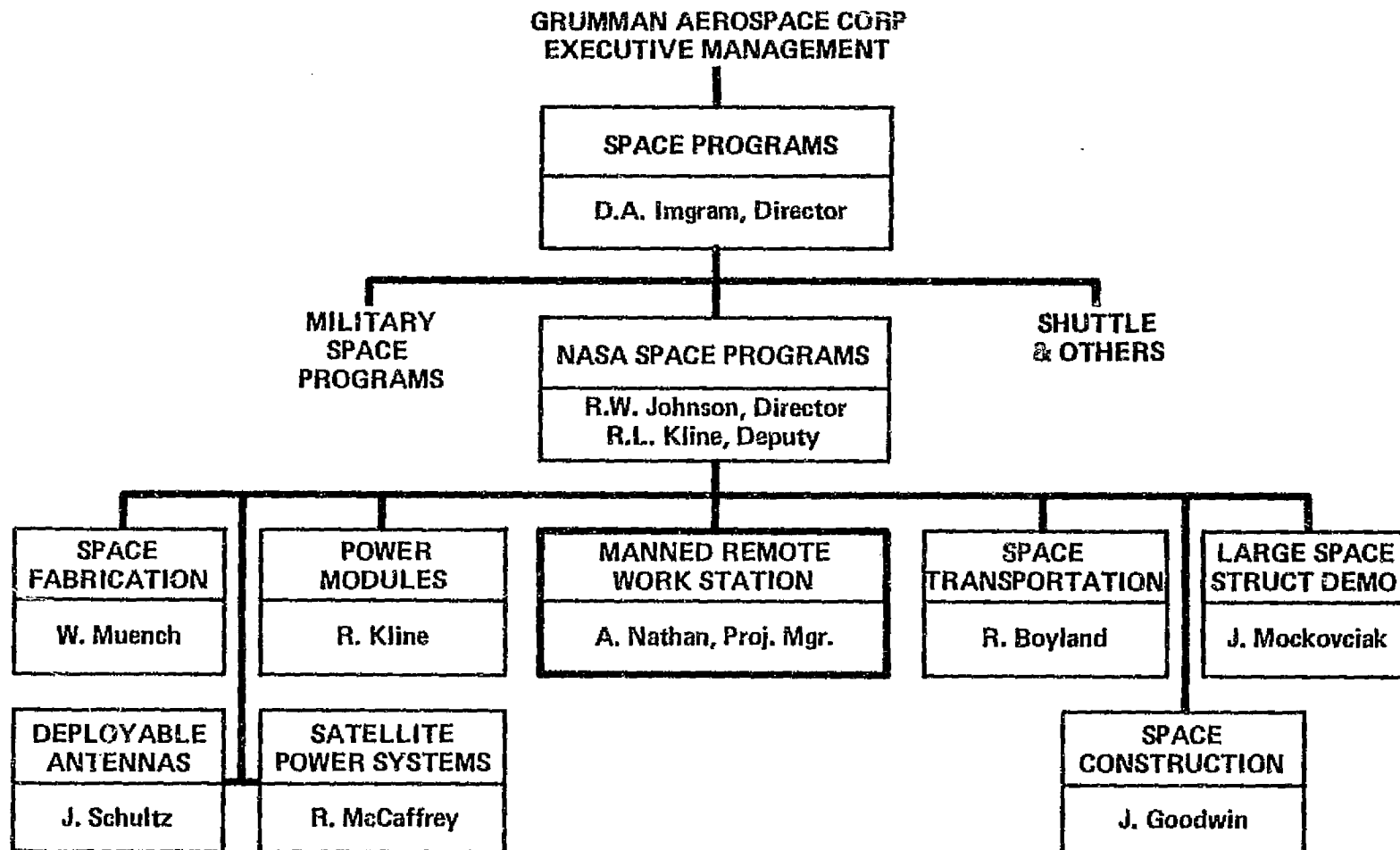
- STUDY OCSE SPS AND NEAR TERM (1980s) CONSTRUCTION SCENARIOS & SHUTTLE SUPPORT FUNCTIONS FOR MRWS MULTI-ROLE REQMTS**
- SPECIFY SIMULATION OBJECTIVES**
- DESIGN ALTERNATE SIM CONCEPTS FOR FULL-SCALE & SUBSCALE TESTING WITH VARYING DEGREES-OF-FREEDOM**
- SELECT INITIAL APPROACH BASED ON COST & SCHEDULE SIMULATOR GROWTH TO PICK UP ALL OBJECTIVES**
- DEVELOP PRELIMINARY DESIGN, SPEC & TEST PLAN FOR SELECTED INITIAL CONCEPT**
- DEVELOP DETAILED DRAWING, MANUFACTURING REQMTS, SCHEDULES & COST**



RELATIONSHIP OF MRWS PROJECT TO GRUMMAN AEROSPACE CORPORATION

The MRWS project is undertaken by a team within the Space Programs organization headed by Donald A. Ingram, Director. Access to Grumman Management is through Mr. Ingram to Ross S. Mickey, Senior Vice President. The relationship of the MRWS team to the Space Programs organization and senior corporate management is shown on the facing page.

RELATIONSHIP OF MRWS PROJECT TO GRUMMAN AEROSPACE CORPORATION



PROGRAM SCHEDULE

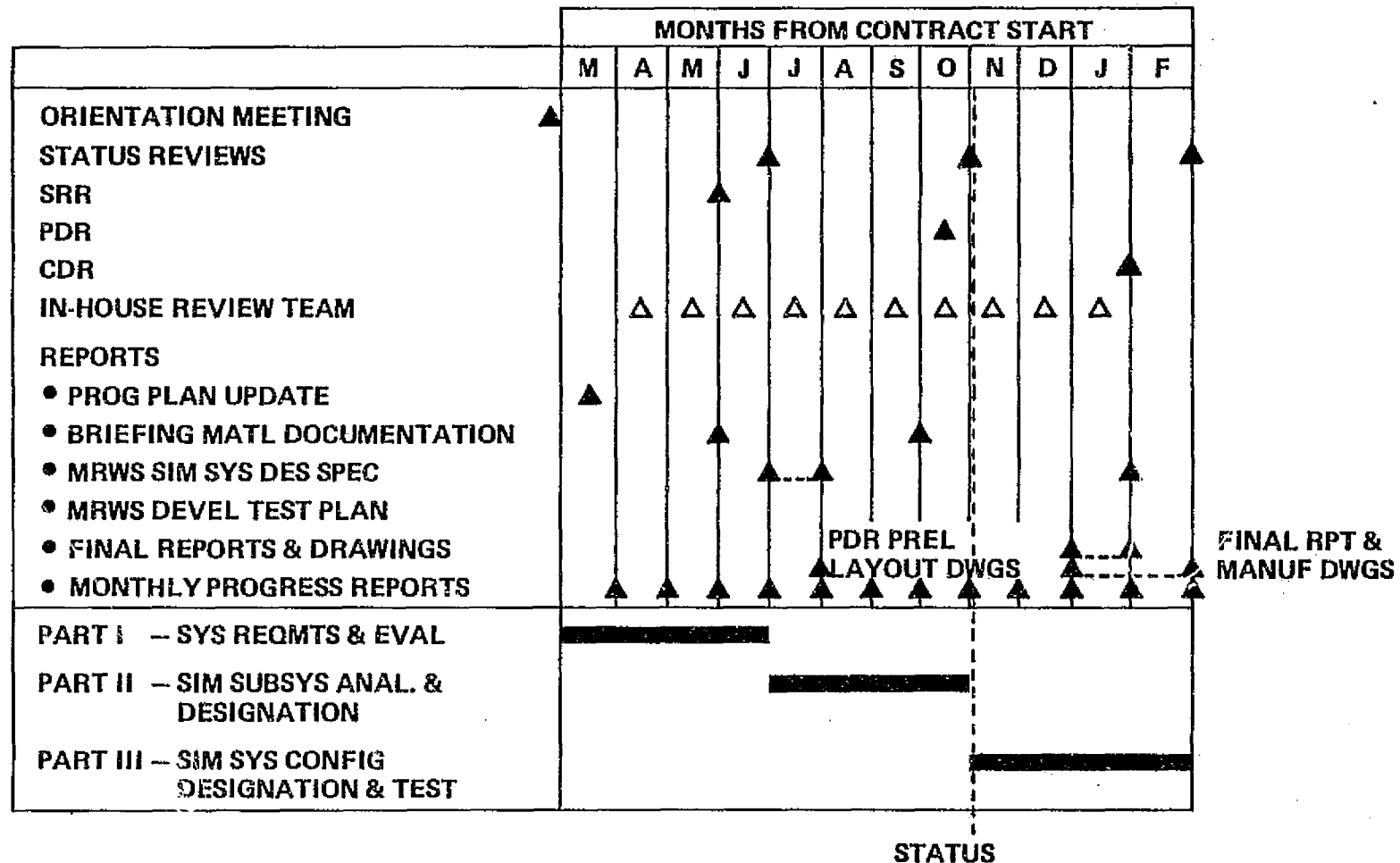
A schedule showing study tasks versus program milestones is shown on the opposite page. Each of the three study parts is scheduled for 4 months. The milestones include NASA review/decision points at SRR, PDR and CDR. Program status reviews are held at the end of the 3rd, 7th and 11th months. In-house MRWS review board meetings are scheduled at mid-monthly intervals prior to NASA reviews.

Part I utilized mission scenarios from past construction studies to define near-term and longer range mission level requirements for an MRWS. After analysis and evaluation of alternate MRWS flight article concepts and subsystems, baseline concepts were selected as the basis for definition of the Development Test Article (DTA). Concept designs for the DTA were prepared, with emphasis on the cherry picker mode, and simulator/DTA growth options evaluated to identify the incremental costs and viability of utilizing the DTA in alternate applications, e.g., as a free flyer. These concepts were evaluated and simulation/DTA requirements defined for the System Requirements Review (SRR).

Part II of the program developed a preliminary design of the DTA based on agreed-upon NASA guidelines emanating from the SRR. Each DTA subsystem (computers, displays, controllers, etc.) was sized and defined to sufficient depth for the Preliminary Design Review (PDR). Analysis and definition of facility integration were also performed and preliminary test requirements for DTA installation and checkout prepared. We are now at the end of Part II of the study.

During Part III of the program, detailed drawings, wiring schematics and installation test procedures are prepared. Cost and scheduling information are developed to a level where, after (CDR) signoff, fabrication/assembly of the DTA can be initiated.

PROGRAM SCHEDULE



PART I: SYSTEM REQUIREMENTS AND EVALUATION

The first two tasks of Part I provided definition of representative MRWS flight articles. The last three tasks generated a simulation concept and a DTA specification. This flow is summarized on the opposite page with the five tasks running a total of four months, including two reviews.

Tasks 1.1 and 1.2 were the focal point of the flight article definition. Its key output was a data package that contains a top level description of the cherry picker flight system and configuration. Expanded OCSE functional analysis of the appropriate operational tasks, as well as an identification of the simulation objectives were included. The configurations, functional analyses, and simulation objectives of the unique features of alternate MRWS roles (crane, free flyer) were treated as deltas.

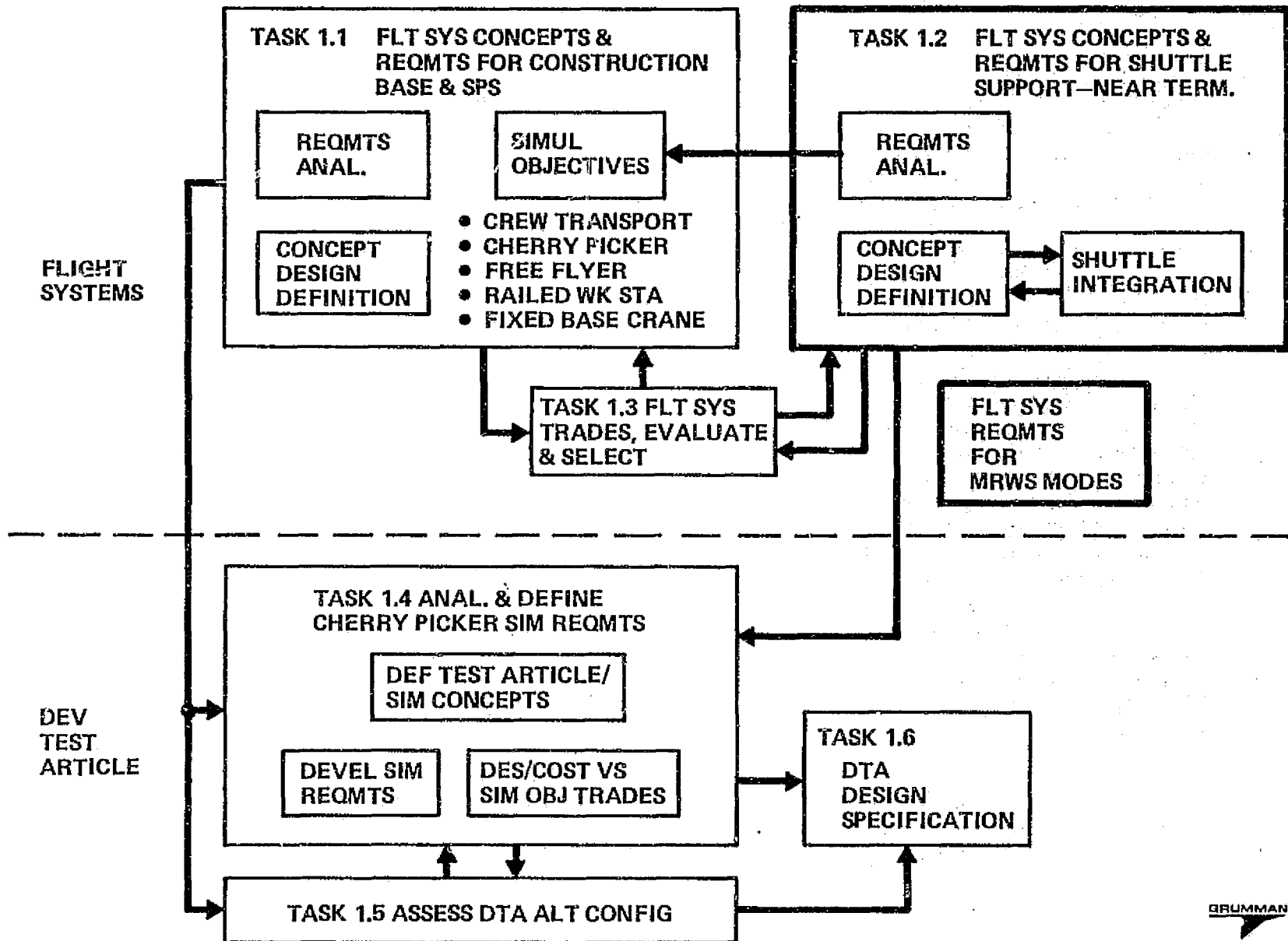
Flight article trades, Task 1.3, were limited to key issues, such as crew size, docking port locations, and the mounting geometry for the external manipulator arms. These were settled early, to minimize later expensive hardware changes on the Development Test Article (DTA). Issues better resolved by the actual simulation program were studied to establish a likely range of options and parameters.

Based on the MRWS flight article data packages, and the capabilities of the MDF, Task 1.4 developed alternative simulation concepts. These concepts focused on the cherry picker role and used various scale and modular DTA buildup approaches to provide development flexibility. Selections were made and reviewed with NASA.

In Task 1.5, unique operations that go with the crane and free flyer MRWS roles were identified and ways of simulating them with least expense explored.

The output of Task 1.6 was the DTA design specification which covers the simulation program and the key subsystems. This specification was based on the flight article data package from Task 1.1, the selected cherry picker simulation concept from Task 1.4, and the added simulation features identified in Task 1.5.

PART 1: SYSTEM REQUIREMENTS AND EVALUATION



GRUMMAN

ORBITAL CONSTRUCTION SUPPORT EQUIPMENT DEVELOPMENT UNIVERSAL MANNED REMOTE WORK STATION

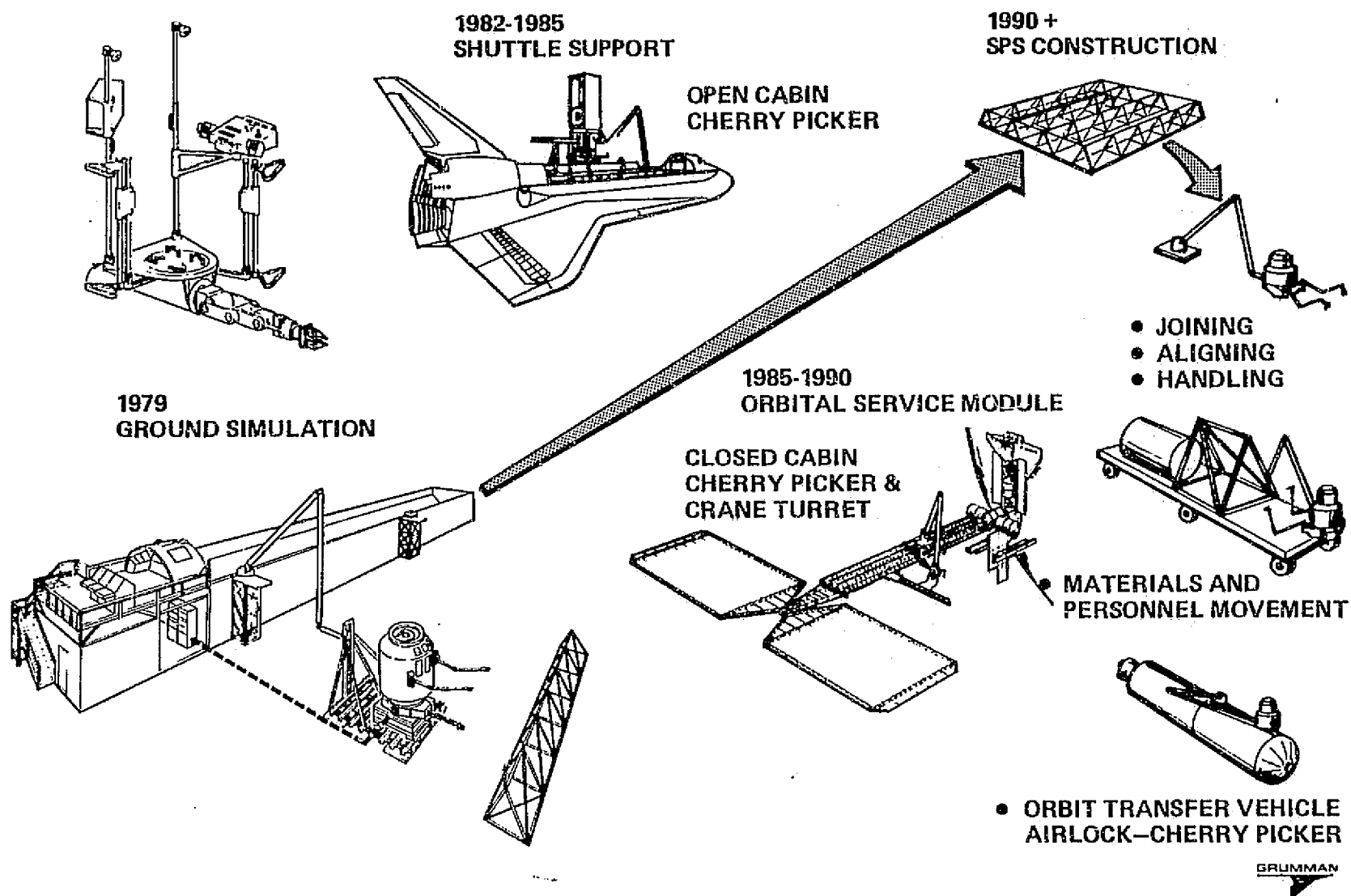
The exploration and utilization of space has witnessed a continuous growth in spacecraft size and weight. Many applications are now envisioned which require ultra-large space structures for implementation. Due to the restrictions of payload and volume limitations of current and projected launch systems, space construction of these ultra-large structures is essential. This report addresses the concepts and application of a key piece of construction equipment needed to support assembly of these large structures. The Manned Remote Work Station (MRWS) is a universal crew cabin to be used as a construction cherry picker, space crane turret, railed work station, or a free flyer. Concepts and requirements for this spacecraft are shown on the opposite page for early applications in support of Shuttle operations, applications in support of a mid to late 1980s construction base, and finally in support of constructing and maintaining the Solar Power Satellite.

Near-term applications of MRWS are in support of Shuttle operations as an open cabin cherry picker mounted to the end of the Shuttle Remote Manipulator System (SRMS). This MRWS provides a platform for EVA servicing of satellites, deployment and retraction of Spacelab experiments, and assembly of large space structures. A small open platform can transport the crew and tools to worksites within reach of the SRMS and provide a stable work station for detailed tasks best performed by astronauts. This device reduces the cost of EVA operations by bypassing the need to man-rate all hardware in the path of the Astronaut during transport to the worksite and would minimize physical contact with the payload once the Astronaut is at the worksite.

In the mid to late 1980s, several planned programs can utilize Manned Remote Work Stations. The initial construction base utilizes an MRWS as a crane turret and as a closed cabin cherry picker for assembly of large antenna and solar power development articles. The longer duration and multi-shift missions will benefit from a CCP in terms of reduced radiation and longer crew work periods.

The ultimate application of the MRWS is in constructing the Solar Power Satellite. The varied roles of the MRWS apply to both Low Earth Orbit and Geosynchronous Orbit operations. The MRWS crane turret and cherry picker is joined in SPS construction operations by free flyers, control center cabins and, railed work stations.

ORBITAL CONSTRUCTION SUPPORT EQUIPMENT DEVELOPMENT UNIVERSAL MANNED REMOTE WORK STATION



OPEN CHERRY PICKER (OCP)

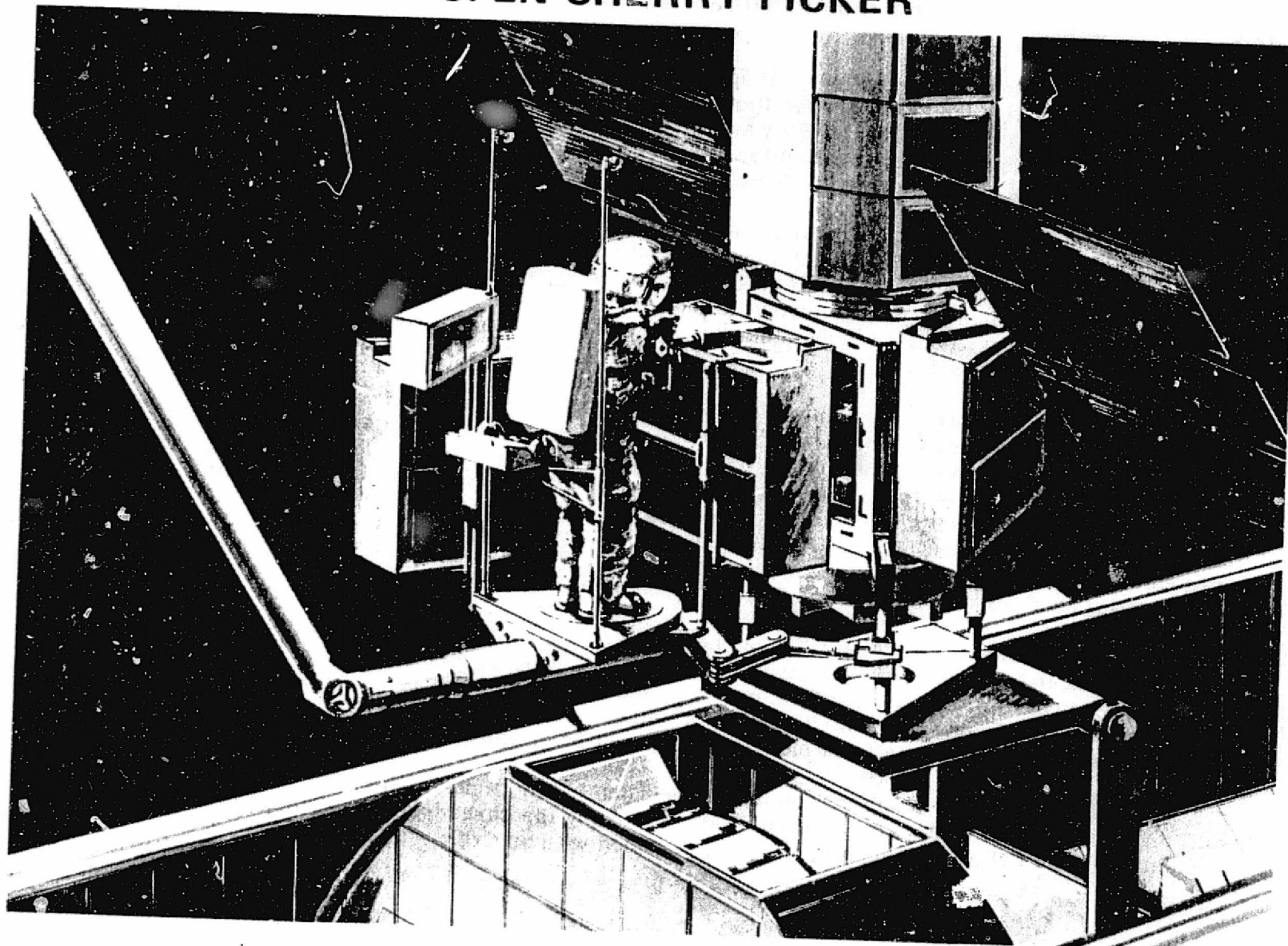
The opposite page shows a rendering of the Open Cherry Picker (OCP) servicing the Multi-Mission Spacecraft. The platform is 91 cm (36 in.) wide and houses a foot restraint assembly on a rotary bearing for full 360 degree rotation by the astronaut. A 6 DOF stabilizer is mounted to the platform and is used to snare a worksite to minimize RMS motions during crew detailed work periods. A control console which includes MMU hand controllers and essential RMS controls and displays is mounted to a swivel. This feature allows the astronaut to rotate the control panel to the rear while working out the front of the cherry picker. Mission peculiar handling devices similar to the clamp mechanism shown for the MMS subsystem module are also mounted to the platform via a rotary joint. Two light stanchions are mounted to the rear of the platform and provide the astronaut with 20 foot candles of illumination at the worksite.

The concept shown is designed with mechanisms so that it can be packaged into a 106 x 152 x 91 cm stowed volume. The OCP is stowed in the forward section of the cargo bay at the structural frames established for the MMU. The overall mass of the OCP is 273 kg including 25% contingency.

Mechanical and electrical interface with the SRMS is through the standard snare-type end effector. The 250 watts of power provided as a payload service at the end effector may be adequate for OCP operations. A data bus system currently available in the SRMS up to the end effector can be utilized for signal interfaces with the OCP. An additional 12 signal lines are also available for dedicated analog signals.

The overall impact of introducing OCP into the Shuttle system is minimal. Development of the OCP also needs no special facilities. The equipments and capabilities already available at such JSC facilities as the Manipulator Development Facilities would be sufficient to flight-qualify the system as well as provide a training facility for the operational system.

OPEN CHERRY PICKER



GRUMMAN

OPEN CHERRY PICKER (OCP) MISSIONS

The opposite page lists potential OCP applications in support of Shuttle operations. A platform mounted at the end of the Shuttle Remote Manipulator System (SRMS) provides a means of conveniently transporting an EVA astronaut, tools and mission hardware about the Shuttle Cargo bay. Similar in application to terrestrial cherry pickers used by power utilities, the OCP will enhance productivity during six hour EVA periods.

The OCP will enhance Spacelab Sortie mission operations by providing a convenient means of deploying and retracting pallet-mounted experiments. The cost of experiments needing mechanical extension desired to clear the cargo bay can be reduced by utilizing EVA assistance in the deployment/retraction operations. The OCP can also position an astronaut who can replace film or recording tapes thereby minimizing the need for data interfaces between experiment and Shuttle.

The concept of in-orbit servicing of automated payloads can be enhanced with use of the OCP. The multi-mission spacecraft with its replacement subsystem modules is particularly suited to service using an astronaut in an OCP. The replacement module and the torque tools needed to withdraw the spent module and insert the new module can all be conveniently located on the OCP. Plans are also being prepared for in-orbit servicing of the Long Duration Exposure Facility (LDEF). The LDEF experiment trays, slightly larger than the MMS subsystem modules, can conveniently be serviced by an OCP. Other automated payloads with potential need for an OCP service are the Space Telescope and HEAO.

The most extensive use of an OCP can be envisioned for support of construction R&D activities using the Shuttle as the construction platform. Many studies performed over the past few years call out the need for EVA crews to deploy assembly fixtures, fasten and align structure, and install subsystems. The OCP provides a convenient means of crew transport and provides a stable work platform once the crew is at a worksite.

An OCP can also have application in the checkout and in-flight repair of the Shuttle itself. All subsystems within reach of the SRMS, including the cargo bay doors, forward-mounted RCS and GN&C equipments, could be serviced with an OCP.

OPEN CHERRY PICKER MISSIONS

FUNCTIONS IN SUPPORT OF SHUTTLE OPERATIONS

• SPACELAB

- DEPLOY & RETRACT EXPERIMENTS
- DATA RETRIEVAL & DATA STORAGE
- SYSTEM RESUPPLY
- UNSCHEDULED MAINTENANCE

• AUTOMATED PAYLOADS

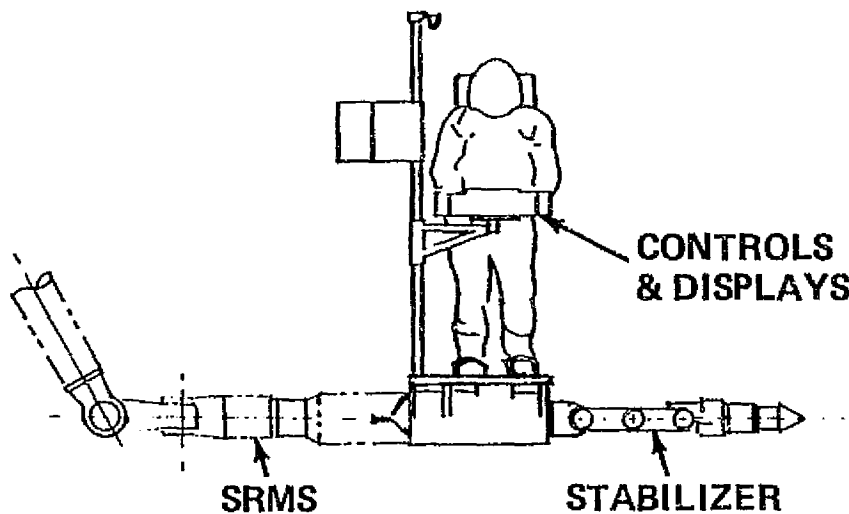
- MMS SUBSYSTEM INTERCHANGE
- LDEF SAMPLE TRAY INTERCHANGE
- LST SERVICING

• CONSTRUCTION R&D

- DEPLOY FIXTURES
- RESUPPLY FAB MACHINES
- JOINING & ALIGN OPERATIONS
- DISASSEMBLE STRUCTURE

• SHUTTLE INSPECTION/REPAIR

- FORWARD RCS
- RADIATORS
- EXPERIMENT TIE DOWN



GRUMMAN

CLOSED CHERRY PICKER

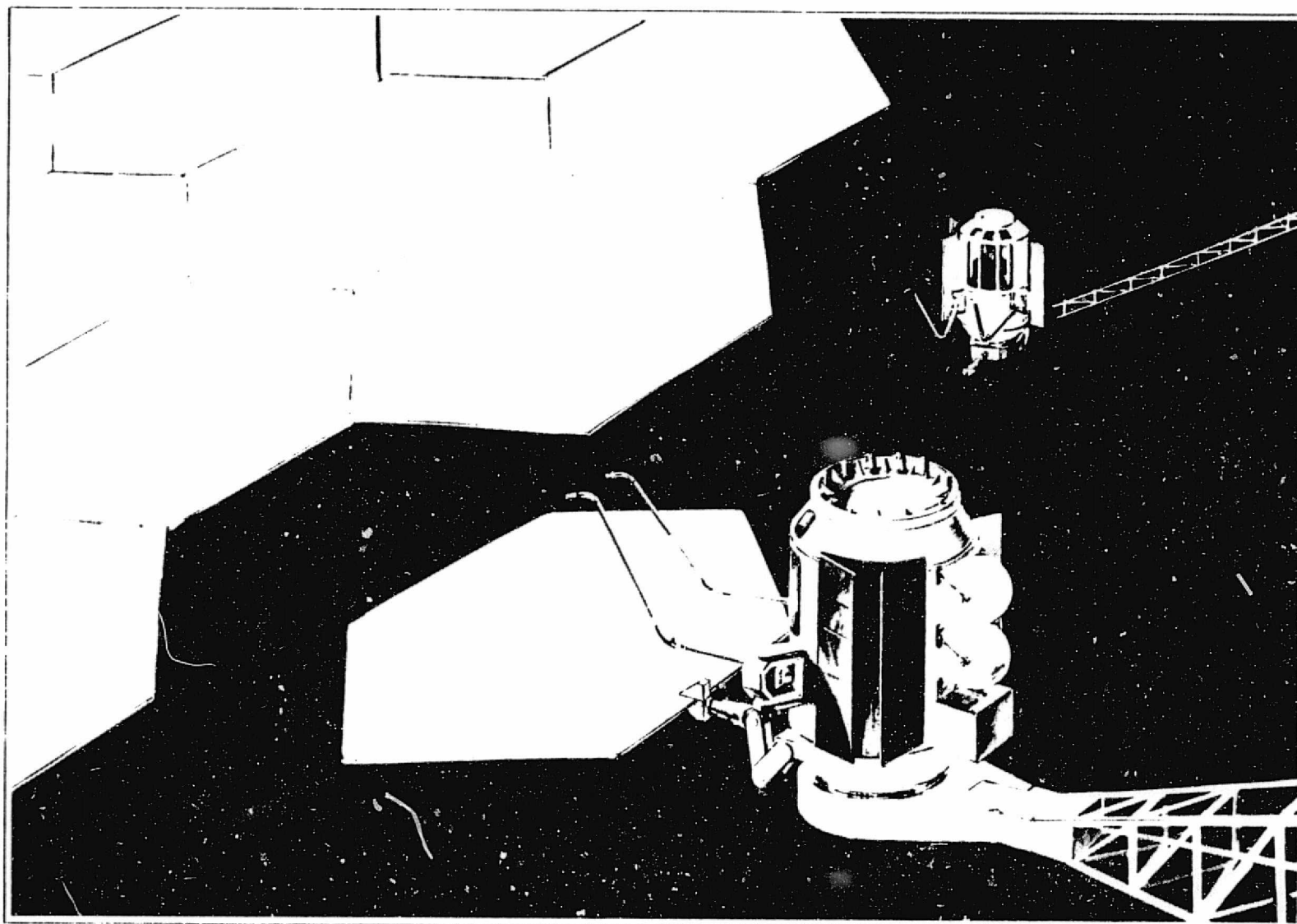
The opposite page displays a rendering of a closed cherry picker (CCP) handling a 4-meter diameter aperture panel for a multi-beam communications antenna. The CCP is configured for one man operation from a single control console utilizing bilateral force-reflecting manipulators. The manipulator slaves are 2 meter long; the masters located in the cabin are 50 cm long. Test data indicates that men operating BFR manipulators have the same productivity as a man in an EVA suit but benefit from the convenience of a shirt sleeve environment and can probably work longer shifts without fatigue.

The CCP has a 170 cm diameter dictated by the need for a 1 m egress hatch at the top and bottom. The cabin height is 49 cm resulting in an internal volume of 4.76 m³. The cabin's atmosphere utilizes a two gas system operated at 14.7 psi. A total of 2.1 m² console area is available for the subsystem controls and displays.

All subsystems are located in an aft equipment bay with a separate heat rejection system. The cabin heat rejection system that operates at 75°-85° F requires 13.4 m² of radiator area. The small size of the cabin requires installation of four deployable two-sided radiator panels.

The overall mass of the CCP is 2244 kg including a 25% contingency. The structure (549 kg) and mechanical system (555 kg) comprise the major portion of the total mass.

CLOSED CABIN CHERRY PICKER

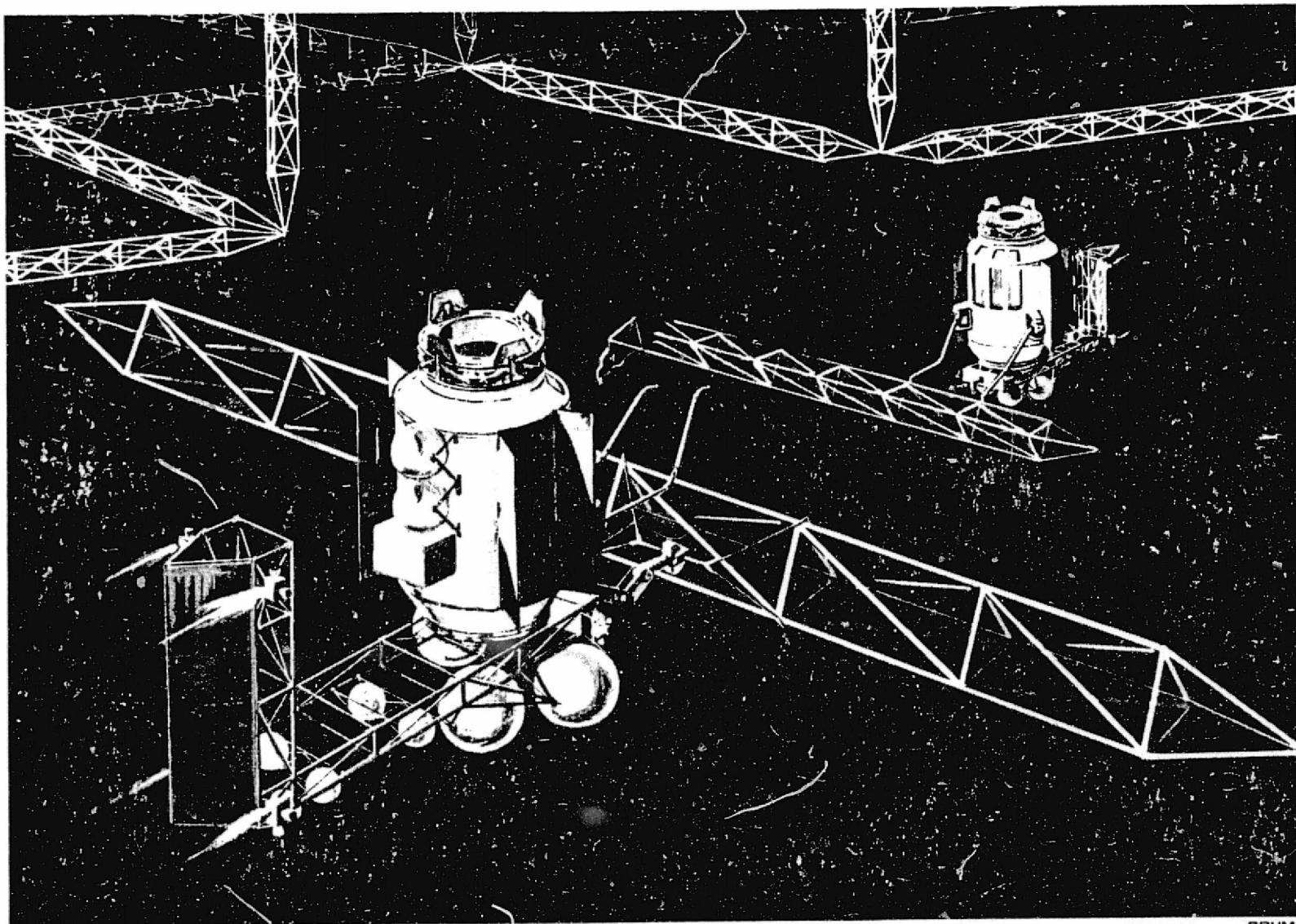


WILMANN

FREE FLYER

A rendering of an MRWS free flyer repairing a damaged structural element is shown on the opposite page. The MRWS cabin is mated to a platform that contains the needed propulsion and electrical subsystems, maintaining a clean transition for the cabin from the roles of cherry picker and crane turret to that of a free flyer. The subsystem elements that must be added to the cabin itself are the GN&C system including a rendezvous sensor and inertial system, as well as added displays of key flight parameters such as range, range rate and line-of-sight rates.

FREE FLYER

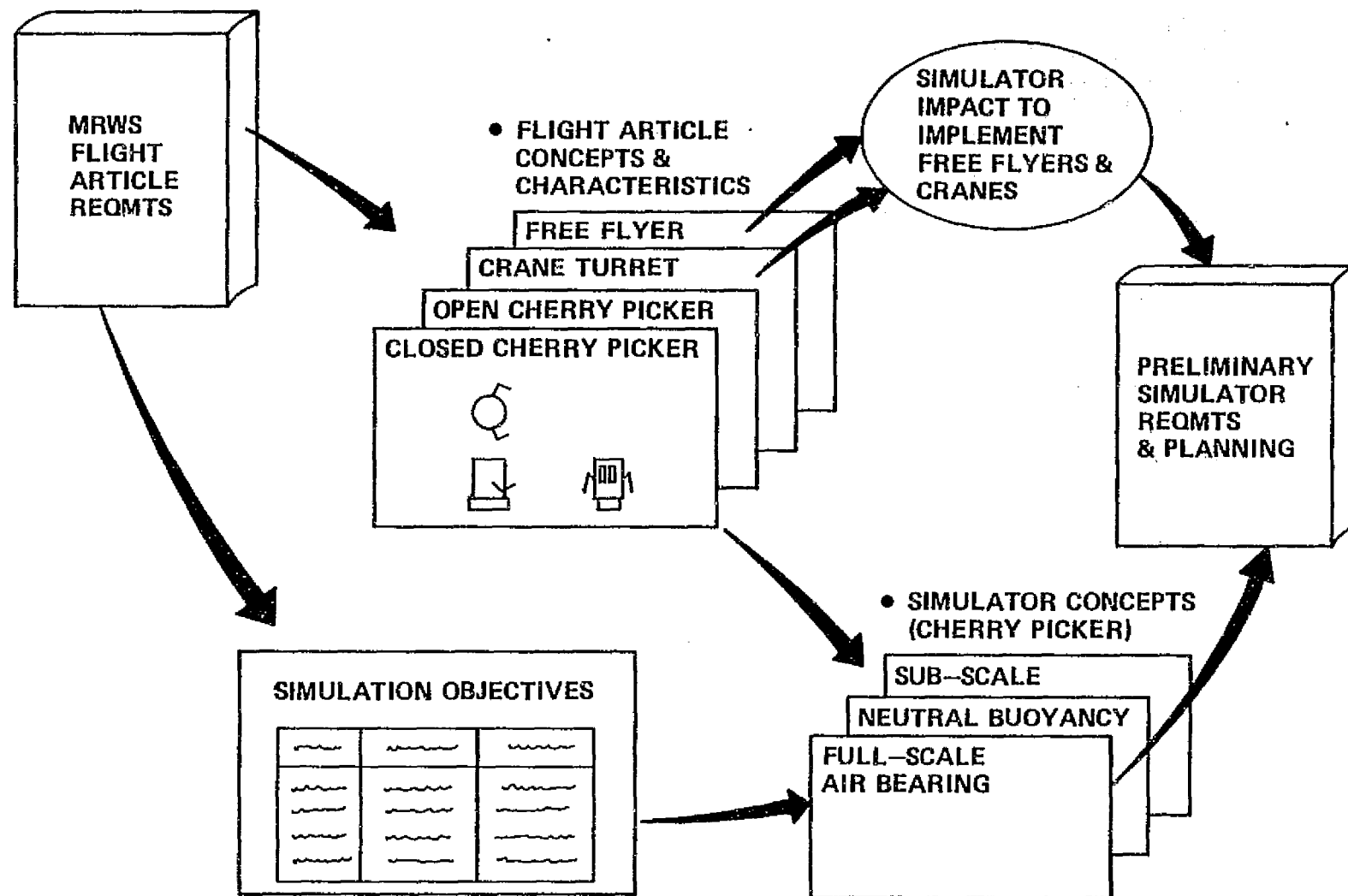


GRUMMAN

SIMULATION REQUIREMENTS DEFINITION APPROACH

The opposite page summarizes the approach used to transform MRWS flight article requirements into simulation requirements. The Flight Article Requirements document, including mission roles for three time phases and supporting tradeoff and evaluation studies were used to identify key issues requiring simulation. These issues were then formatted into simulation objectives which were analyzed for the type of simulator needed to meet the objectives. These simulator concepts were broken down into full-scale simulations using an air bearing, neutral buoyancy simulations, and sub-scale simulators. Those falling into the category of full-scale simulation were used to prepare Preliminary Simulator Requirements and Plans.

SIMULATOR REQUIREMENTS DEFINITION APPROACH



GRUMMAN

SIMULATOR PROGRAM OPTIONS

Two simulator program options were studied that provide a growth in simulator capability over the next five years. The first approach (shown on the opposite page) is centered around a concept of modular buildup of the Development Test Article so that both the open cherry picker and closed cherry picker can be evaluated using the same hardware. In the second option, two dedicated DTAs are fabricated; the first is a high fidelity version of the open cherry picker and the second is a high fidelity article of the closed cherry picker.

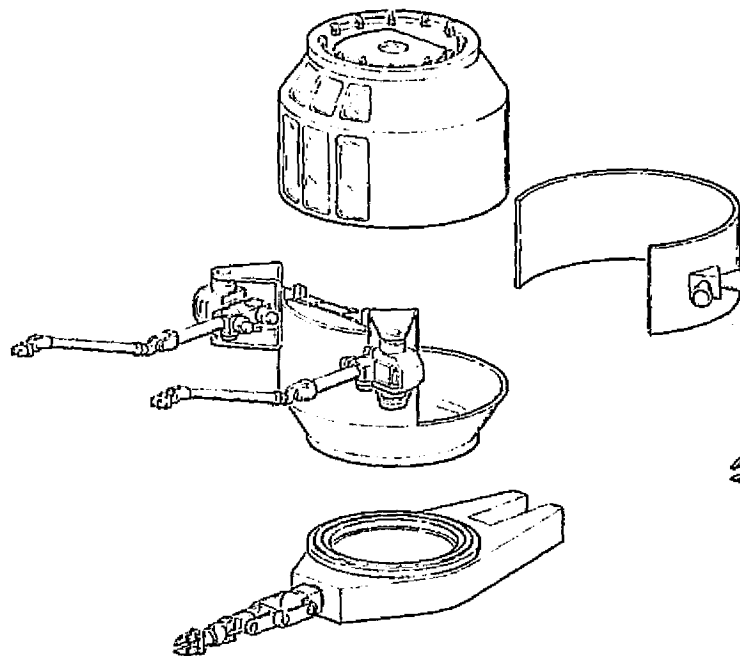
Program Option 1 stresses modularity in which the lower sections of the DTA are used in open cherry picker simulation. After two years of operation as an open cherry picker, the upper sections of the DTA including the supporting controls and displays are added.

Program Option 2 emphasizes early development of the open cherry picker by fabricating a DTA that is functionally and geometrically the same as the expected flight article. This is followed by fabrication of a closed cherry picker that is not compromised by open cherry picker functions.

It was recommended that program Option 2 be selected. This program supports the development requirements for the flight article by emphasizing open cherry picker design. This program also provides a one year period for design and fabrication of dexterous manipulators. A survey of existing BFR manipulator designs indicate that a new design that is based on existing techniques and components was needed.

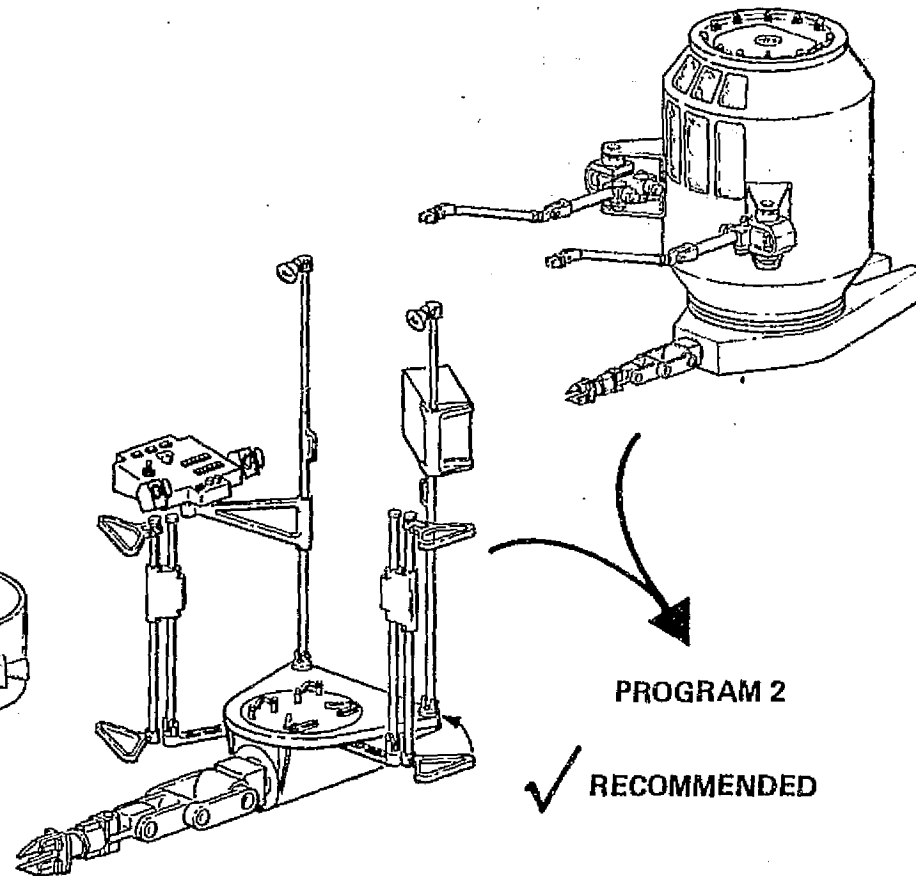
SIMULATOR PROGRAM OPTIONS

PROGRAM 1



PROGRAM 2

✓ RECOMMENDED



ORIGINAL PAGE IS
OF HIGH QUALITY

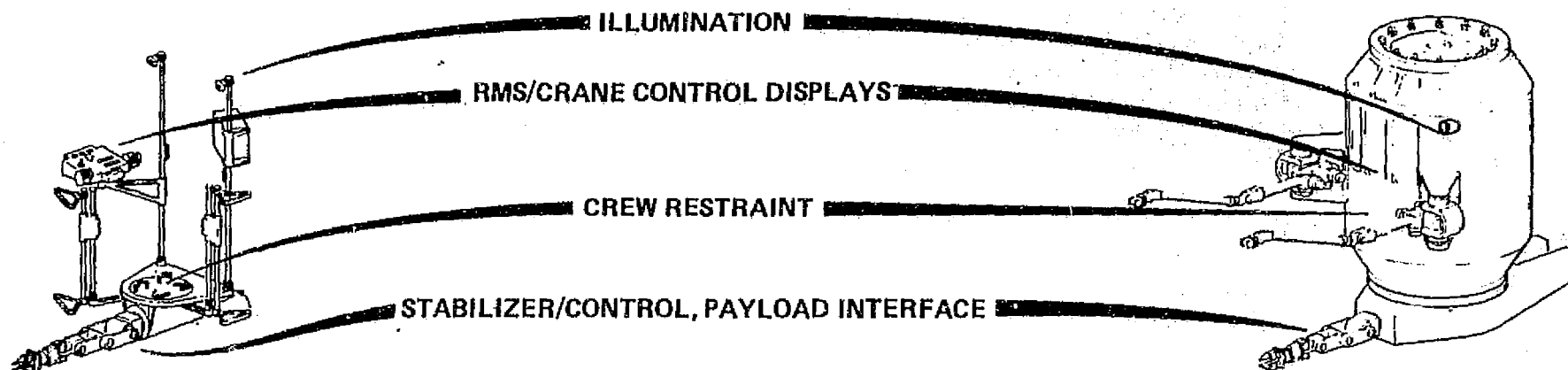
GRUMMAN

TECHNOLOGY FOLLOW-THRU FROM OPEN CP TO CLOSED CP

The facing page summarizes the elements and technologies that carry over from the open cherry picker to the closed cherry picker. The major hardware developments include design of the stabilizer, display and control system functions, crew restraint systems and the lighting system. Functional similarities between the open cherry picker and closed cherry picker are the control of two crane arms from the cherry picker, techniques for obstacle avoidance and determination of a standard of performance in terms of time for construction that must be bettered by the closed cherry picker.

The significant level of technology carryover supports selection of designing, fabricating and operating the lower cost open cherry picker first, and then utilizing the lessons learned in the design of a closed cherry picker.

TECHNOLOGY FOLLOW-THRU FROM OPEN CP TO CLOSED CP



FUNCTIONAL TRANSFER

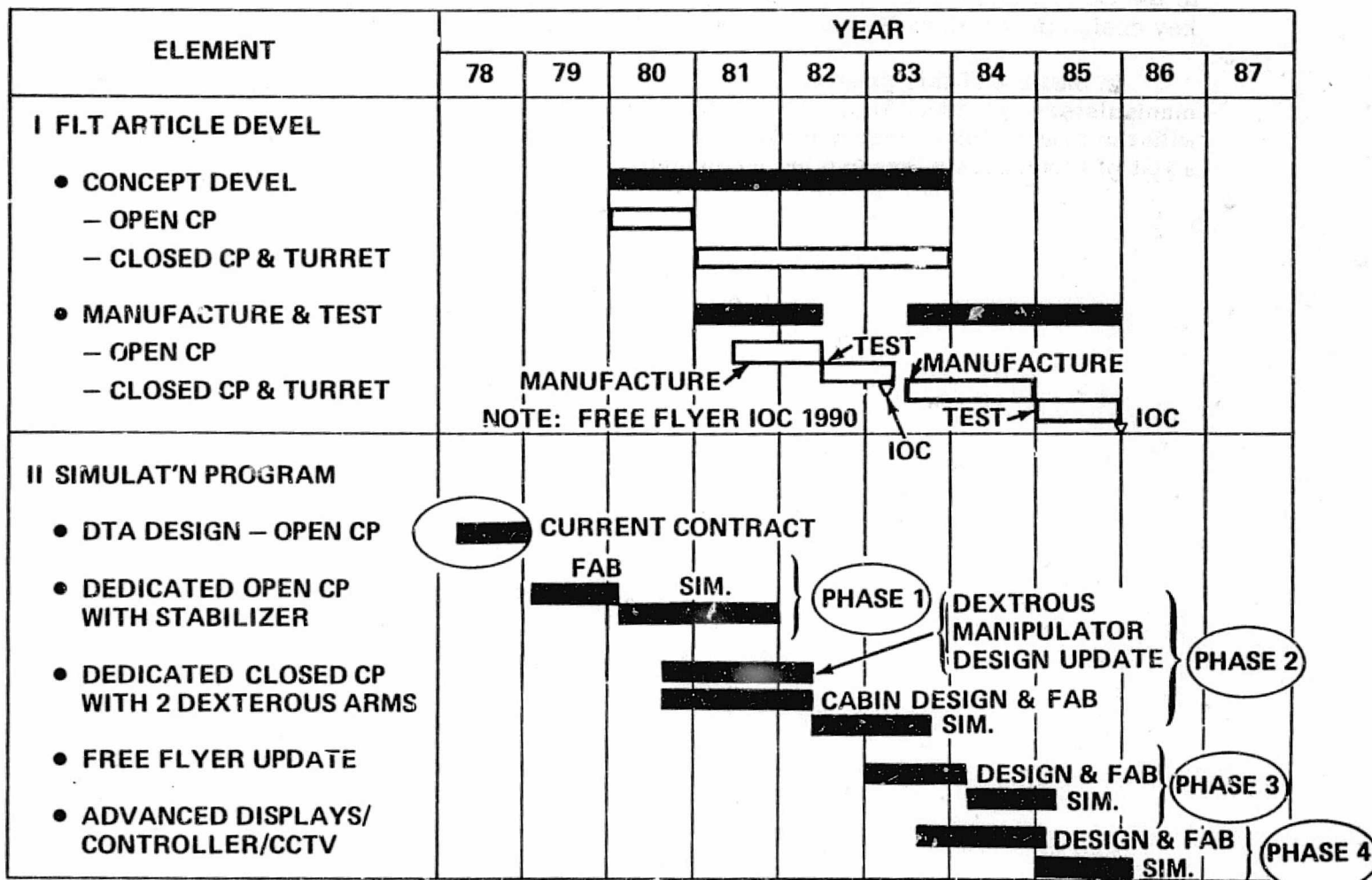
- CONTROL OF SECOND RMS/Crane
- PARALLEL OCP & RMS/Crane OPS
- OBSTACLE AVOIDANCE
- DESIGN LOADS
- STRUCTURE & SUBSYSTEM ASSY PROCEDURES
- WINDOW VISIBILITY
- CONSTRUCTION TIMELINES



DEVELOPMENT SCHEDULE

A summary of the phases in the selected program and how the simulation program phases with the flight article development and manufacture is shown on the opposite page. Design of a dedicated open cherry picker is performed under the current contract and built in 1979. Open cherry picker testing is then performed in 1980 and 1981 to support OCP concept development. Manipulator design and fabrication is performed in 1980 in parallel with design and fabrication of the closed cherry picker cabin. Testing of the CCP is initiated in 1982 and reconfigured in 1983 to perform free flight testing. Advanced controls and displays are added and tested in 1984 in time to support CCP concept development.

DEVELOPMENT SCHEDULE



ORIGINAL PAGE IS
OF HIGH QUALITY

DEVELOPMENT TEST ARTICLE: PROGRAM PHASES

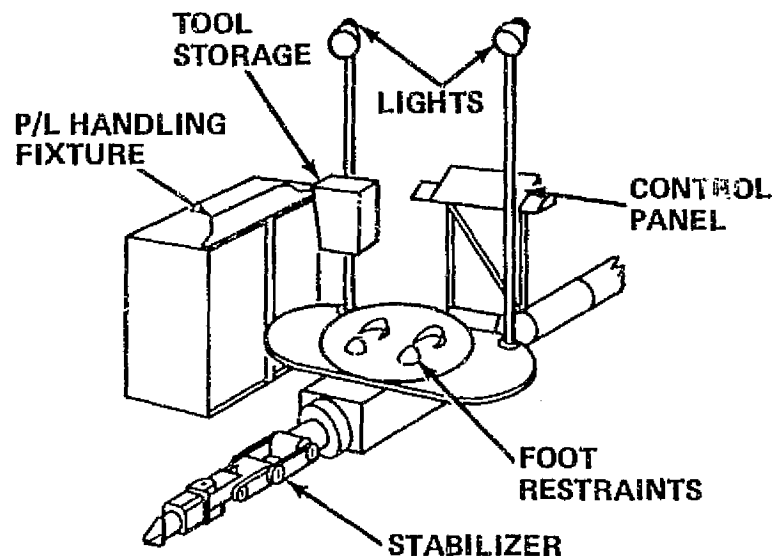
The selected program begins with deployment of a dedicated high fidelity open cherry picker including the stabilizer and special handling fixtures. Test to determine approaches to the OCP/SRMS control interface and the stabilizer operations should be emphasized. Other key design parameters that are investigated include design loads and lighting requirements.

In phase 2 of this program, a dedicated closed cherry picker including two dexterous manipulators are added to the MDF. The stabilizer used in the OCP tests can be interchanged with the newer closed cherry picker. Included with the illustration on the opposite page is a list of typical tests that can be performed.

DEVELOPMENT TEST ARTICLE

PHASE 1

DEDICATED OPEN CHERRY PICKER

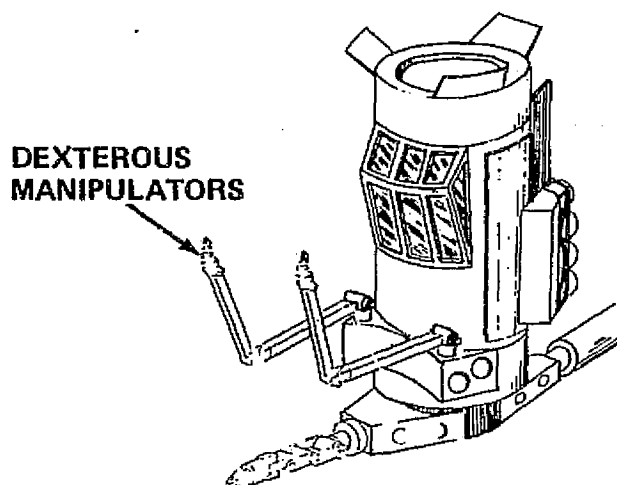


TEST TO DETERMINE:

- RMS CONTROL APPROACH INCLUDING OBSTACLE AVOIDANCE
- DESIGN LOADS
- PARALLEL OCP/RMS OPERATIONS
- SUBSYSTEM INSTALLATION PROCEDURES
- STRUCTURAL ASSEMBLY PROCEDURES
- LIGHTING REQUIREMENTS
- WORK DURATION & TIMELINES

PHASE 2

DEDICATED CLOSED CABIN CHERRY PICKER



TEST TO DETERMINE:

- DEXTEROUS MANIPULATOR PERFORMANCE USING MASTER VARY
 - MASTER FORCE
 - MASTER INDEXING SCHEMES
- HUMAN FACTORS
 - METABOLIC WORK LOAD
 - WORK DURATION
- WORKSITE FACTORS
 - ACCESSIBILITY
 - MANIPULATOR LENGTH
- STABILIZER OPERATIONS/DESIGN LOADS
- LIGHTING REQUIRED
- STRUCTURAL ASSEMBLY PROCEDURES
- SUBSYSTEM INSTALLATION PROCEDURES

GRUMMAN

ORIGINAL PAGE IS OF POOR QUALITY

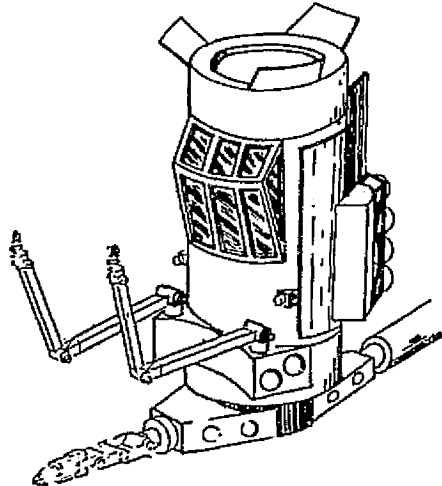
DEVELOPMENT TEST ARTICLE: PROGRAM PHASES

Hardware and testing requirements for Phases 3 and 4 are summarized on the opposite page. In Phase 3, jets, control electronics and gas system are added to meet requirements for free flyer simulation. Advanced controls and displays are added to the system in Phase 4.

DEVELOPMENT TEST ARTICLE

PHASE 3

ADD FREE FLYER CAPABILITY



DTA MODIFICATIONS

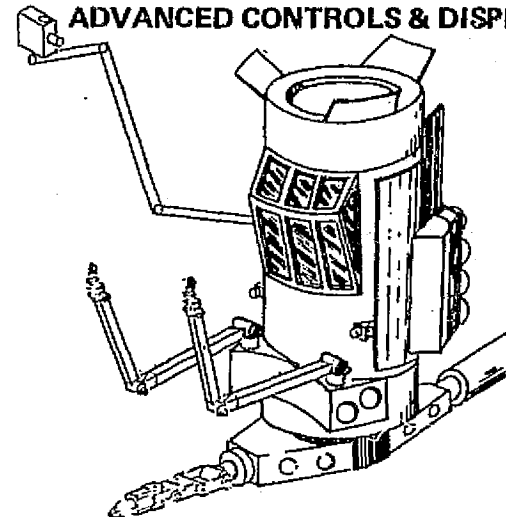
- ADD
 - THRUSTERS
 - CONTROL ELECTRONICS

TEST TO DETERMINE:

- STABILIZER OPERATIONS DURING FREE FLIGHT
- MANIPULATOR OPERATIONS DURING FREE FLIGHT
- AUTO STATION KEEPING GUIDANCE REQUIREMENTS
- RESCUE OPERATIONS

PHASE 4

ADVANCED CONTROLS & DISPLAYS



DTA MODIFICATIONS

- ADD
 - EXTERNAL FLOOD LIGHTS
 - BOOM MOUNTED LIGHTS & STEREO TV
 - INTEGRATED CONTROLS & DISPLAYS
 - ADVANCED MANIPULATOR CONTROLLER

TEST TO DETERMINE:

- EFFECTS OF STEREO TV ON ASSEMBLY OPERATIONS
- ASSEMBLY DISPLAY REQUIREMENTS & FORMATS
- PRODUCTIVITY WITH ADVANCED CONTROLLER



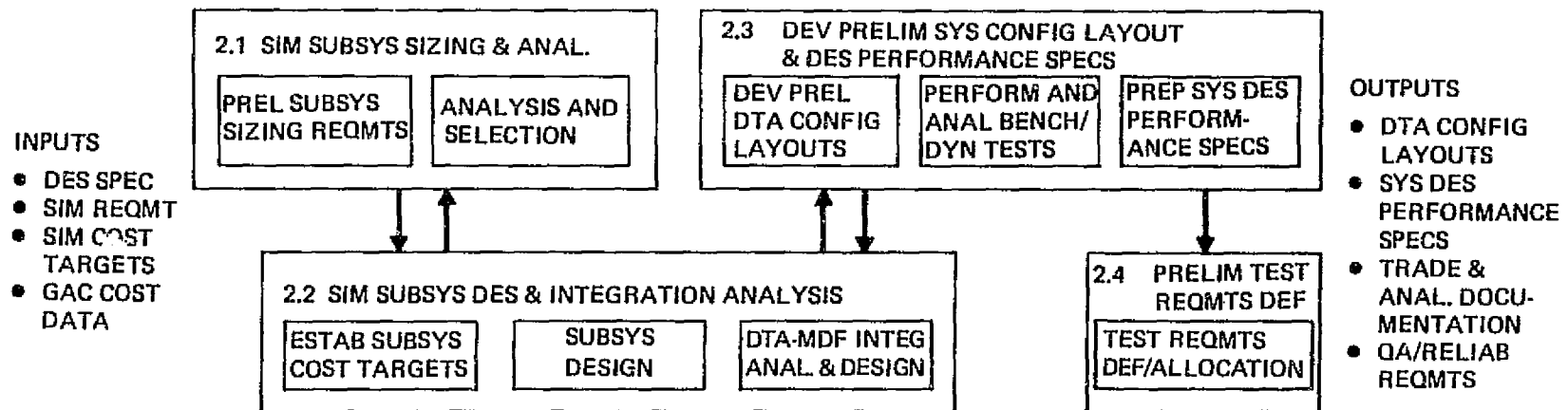
PART II - SIMULATOR SUBSYSTEM ANALYSIS AND DESIGN

The key output of Part I was the selection of the open cherry picker as the program element that will be emphasized in early simulation. Part II of the effort, just completed, has performed the tasks listed on the facing page to provide a preliminary design of an open cherry picker Development Test Article and performance specifications for review at PDR. Included as part of the process was the integration of the DTA with the manipulator development facility. Particular attention was given to the test requirements during actual simulation to determine the flexibility that must be designed into the DTA to meet simulation objectives.

PART II – SIMULATOR SUBSYSTEM ANALYSIS AND DESIGN

TASK OBJECTIVES:

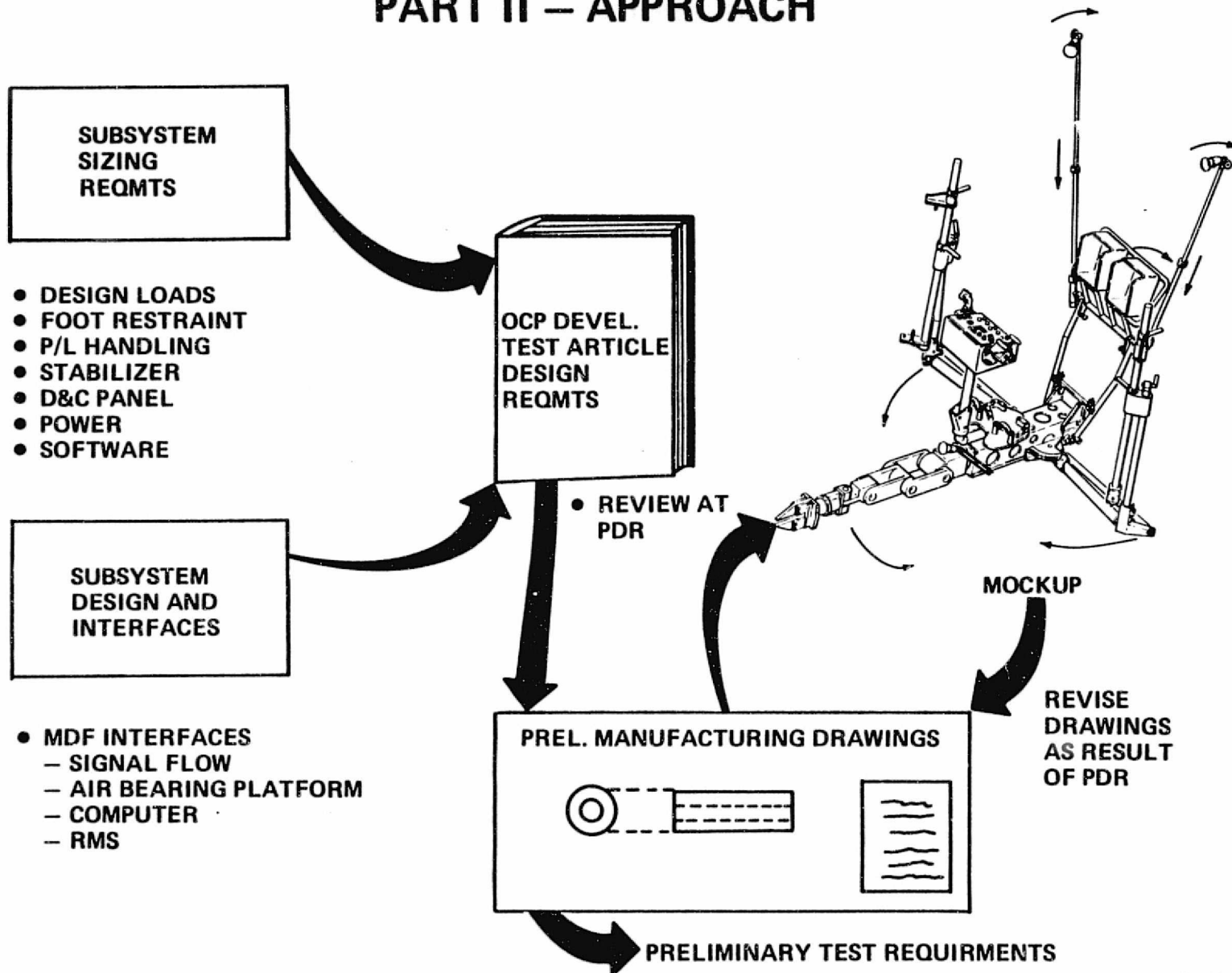
- TASK 2.1 – DETAIL SUBSYSTEM SIZING AND ANALYZE SIMULATOR PERFORMANCE
- TASK 2.2 – INTEGRATION OF SIMULATOR SUBSYSTEMS
- TASK 2.3 – PROVIDE PRELIMINARY SYSTEM LAYOUTS & DESIGN PERFORMANCE SPECIFICATION – INTEGRATE HARDWARE BENCH TESTS & DYNAMIC TESTS INTO SYSTEM DESIGN & SPECIFICATION
- TASK 2.4 – DEFINE PRELIMINARY TEST REQUIREMENTS FOR EQUIPMENT CHECKOUT



PART II - APPROACH

The approach used during Part II is summarized on the facing page. The results of subsystem sizing analysis, design, and interface evaluations were compiled into a DTA design requirements document. This document was then used to generate preliminary manufacturing drawings for the fabrication of a hard markup for review at the PDR. The PDR results will now be factored into a revised set of manufacturing drawings and design specification during Part III of the effort.

PART II – APPROACH



ORIGINAL PAGE IS
OF PAPER QUALITY

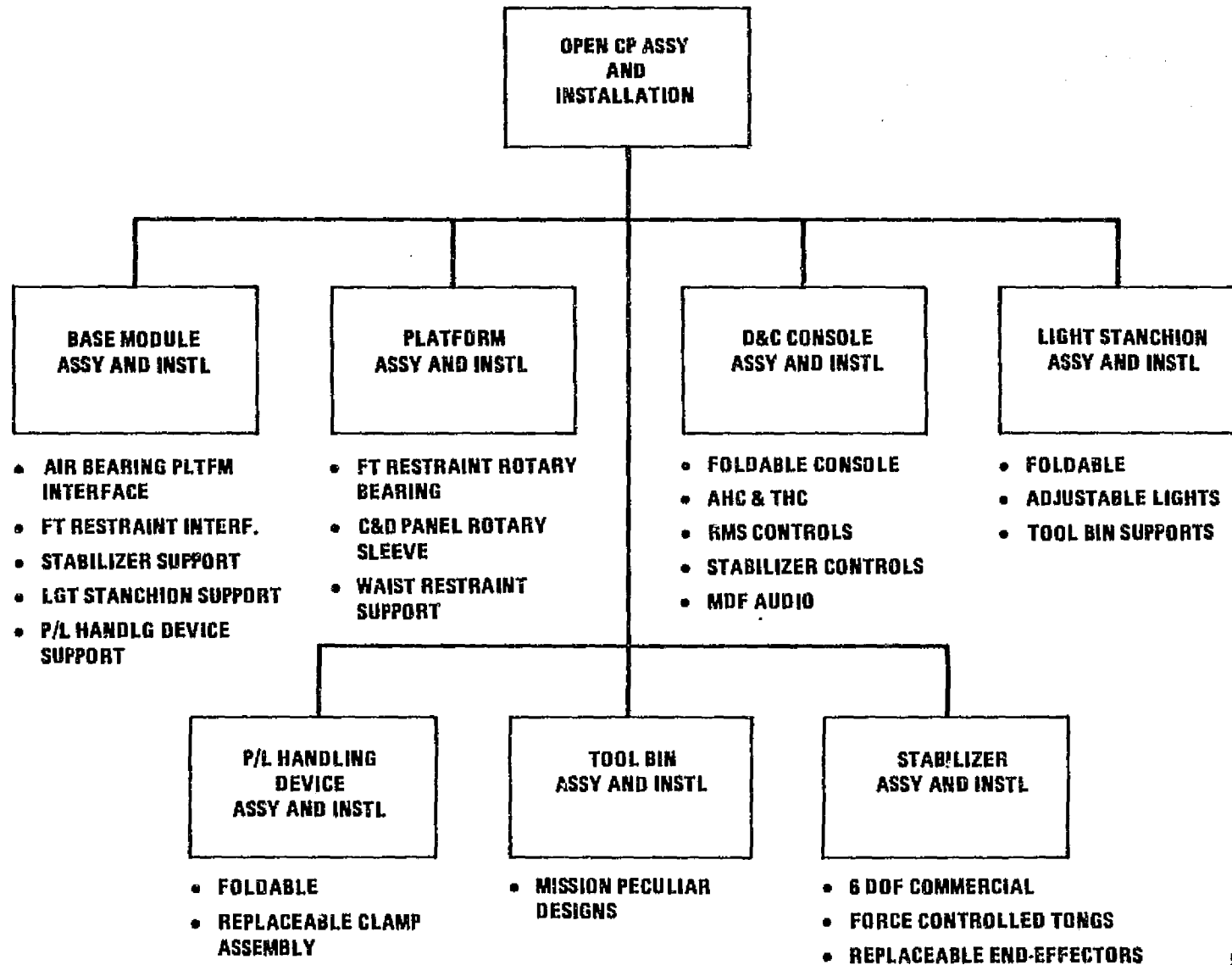
GRUMMAN

DEVELOPMENT TEST ARTICLE WBS

The Work Breakdown Structure for the Development Test Article hardware components are listed on the facing page. There are seven major subassemblies including the base module, platform, D&C panel, light stanchion, payload (P/L) handling device, tool bin and stabilizer.

The base module is a structural strong back that supports the platform, stabilizer and light stanchion. The platform houses independent rotary bearings for the D&C console and foot restraint system. The D&C panel contains the indicators, switches and controllers for monitor and control of the RMS, stabilizer, lights and facility intercom, while the light stanchion contains mechanism for locating two lights at a wide variety of positions and angles. The light stanchion also houses the tool bin which is split into two sections. One section houses simple hand tools while the second provides storage for medium sized mission peculiar tools such as the Multi-Missions Spacecraft module interchange tool. The stabilizer is a 6 degree-of-freedom commercial manipulator which is approximately 5 ft long that features variable force control on the end-effector as well as easy replacement of the end-effector.

DEVELOPMENT TEST ARTICLE WBS

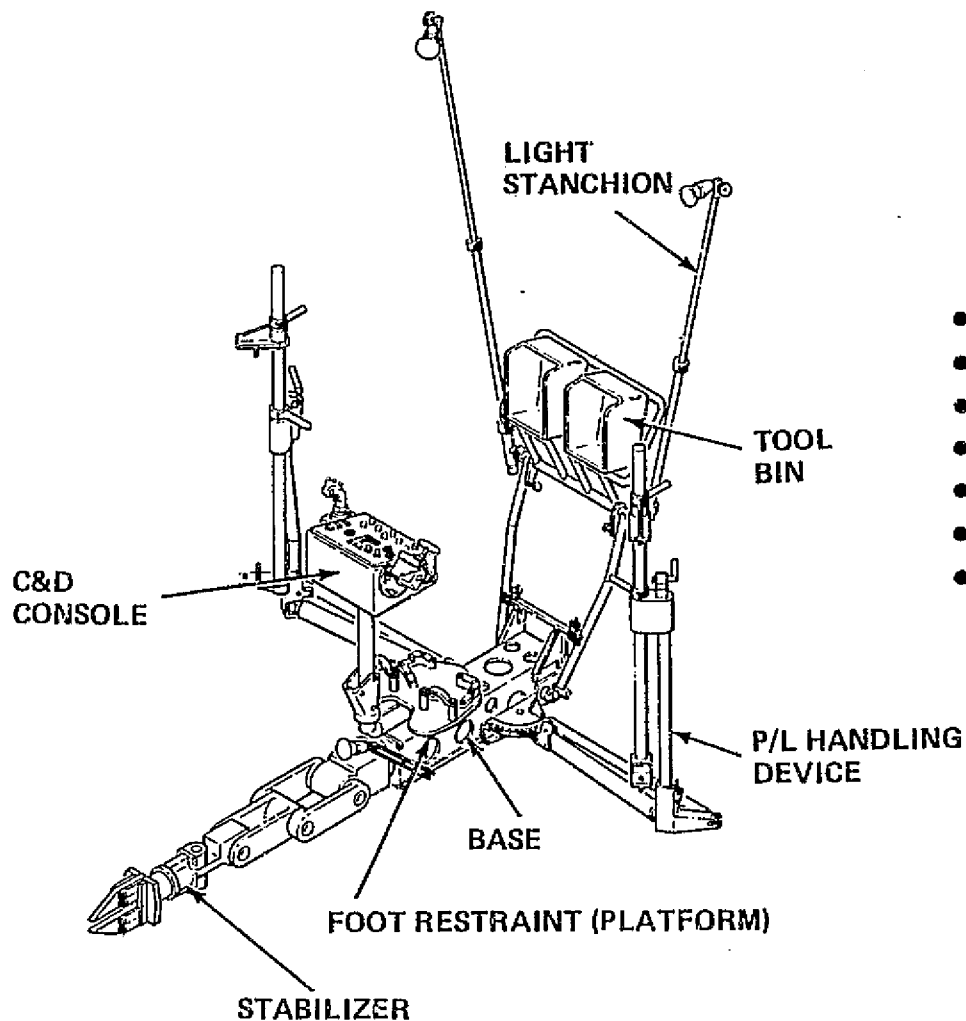


GRUMMAN

OPEN CHERRY PICKER DEVELOPMENT TEST ARTICLE

The facing page presents an isometric drawing of the development article indicating the major hardware elements discussed previously. Also included is a weight breakdown of the system. The system weight is 547 lb. with the stabilizer contributing 200 lb. The total weight is well within the lift capability of the airbearing platform at the JSC Manipulator Development Facility.

OPEN CHERRY PICKER DEVELOPMENT TEST ARTICLE



- BASE MODULE
- PLATFORM
- D&C CONSOLE
- LIGHT STANCHION
- P/L HANDLING DEVICE (2)
- TOOL BIN
- STABILIZER

TOTAL

**WEIGHT,
LB**

25.0

28.0

80.0

55.0

120.0

39.0

200.0

547.0

KEY ISSUES ADDRESSED AT PDR

The facing page lists some of the key issues addressed at the preliminary design review (PDR) held on October 24th (1978). These issues include selection of a concept for mounting the stabilizer to the base module, selection of a waist restraint system and selection of a design approach to the D&C panel including type of hand controller, panel height and interface with the facility intercom system. Consideration of the size and types of tools to be stowed on the cherry picker was also at issue and will be delineated in second section of this report. Design requirements for the payload handling device was also at issue and will be discussed in the 3rd section of this report. Of major importance was the selection of the type of stabilizer to be used in the development test article. Selection of a commercial device was considered the low cost approach that provided the flexibility to determine ultimate flight article stabilizer requirements.

KEY ISSUES FOR RESOLUTION AT PDR

- **BASE MODULE ASSEMBLY AND INSTALLATION**
 - STABILIZER MOUNTING
- **PLATFORM ASSEMBLY AND INSTALLATION**
 - WAIST RESTRAINT DESIGN
- **D&C CONSOLE ASSEMBLY AND INSTALLATION**
 - WITH OR WITHOUT HAND CONTROLLERS?
 - INTERCOM LOCATION
- **TOOL STORAGE**
- **P/L HANDLING DEVICE ASSEMBLY AND INSTALLATION**
 - RANGE OF P/L SIZES AND SHAPES TO BE HANDLED
- **STABILIZER ASSEMBLY AND INSTALLATION**
 - OFF-THE-SHELF OR NEW DESIGN?



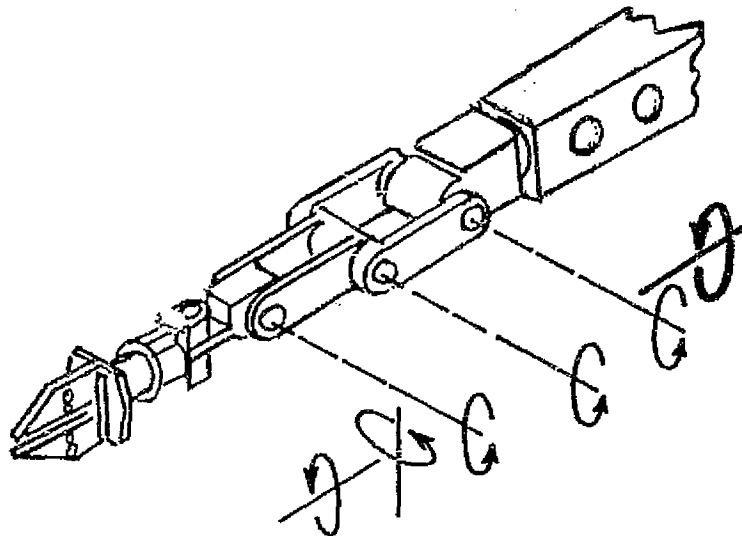
STABILIZER MOUNTING OPTIONS

The two stabilizer mounting arrangements considered are shown on the facing page. The arrangement on the left, mounts the shoulder center line along the center line of the base module, while the arrangement on the right, mounts the shoulder center line perpendicular to the base module center line. In both cases, computational singularities exist when the stabilizer arm is extended directly in front of the base module. However, the packaging arrangement, of the shoulder roll option is cleaner, and the shoulder roll motion provides a reach-around capability not evident in the shoulder yaw mounting option.

Based on these operational and configuration tradeoffs, the "shoulder roll" option was selected for implementation.

STABILIZER MOUNTING OPTIONS

SHOULDER ROLL



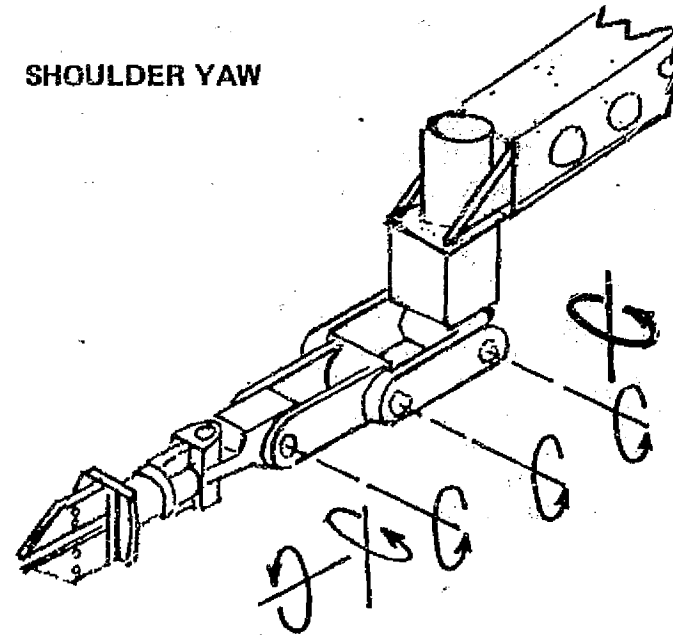
- LONGITUDINAL SINGULARITY
- SIMPLE MECHANICAL INTERFACE
- MAXIMUM REACH AROUND
- COMPACT STOWING



SELECTED

- SELECTION RATIONALE:**
- OPERATIONAL CAPABILITY
 - MECHANICAL INTEGRATION

SHOULDER YAW



- LONGITUDINAL SINGULARITY
- MOUNTING BRACKET REQUIRED
- REACH OVER/UNDER ONLY
- RMS-LIKE OPERATION
- SHORTER REACH

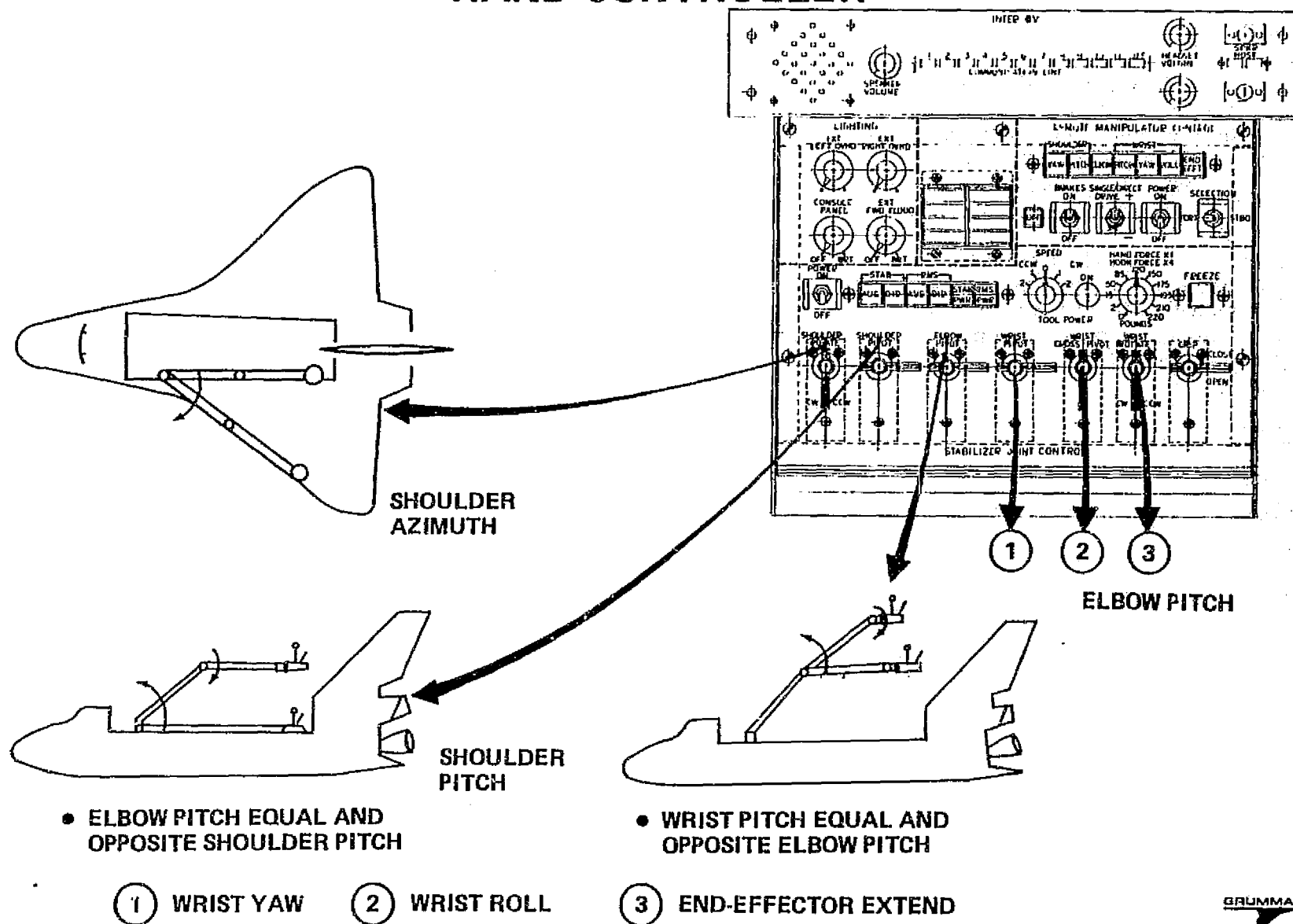


ALTERNATE RMS CONTROL SYSTEM W/O HAND CONTROLLERS

One of several issues associated with design of the Display and Control panel (D&C panel) is outlined on the facing page. Because of the potentially high cost of hand controllers, alternates to use of the standard space attitude and translational hand controllers were evaluated. The scheme shown on the facing page utilizes six levers for each of the six joints of the RMS. This approach, similar to the method used on terrestreal cherry pickers, is simple and efficient once the operator learns to utilize two or three levers simultaneously.

Each lever is hardwired to the RMS drive electronics, rather than routed through the Shuttle General Purpose Computer. A simple control algorithm, could be implemented at the OCP D&C panel itself. In this control scheme, the shoulder yaw lever commands a proportional yaw rate signal to the RMS, while a shoulder pitch lever motions, commands a rate to the RMS shoulder pitch actuator and an equal and opposite signal to the elbow pitch actuator. This later command maintains the upper arm in a fixed orientation to the Shuttle. An elbow lever motion, commands a RMS elbow pitch motion and an equal and opposite wrist pitch motion, maintaining as a result, a fixed cherry picker orientation relative to the Orbiter.

ALTERNATE RMS CONTROL SYSTEM WITHOUT HAND CONTROLLER



ORIGINAL PAGE IS
OF POOR QUALITY

STABILIZER: COMMERCIAL OR NEW BUILD?

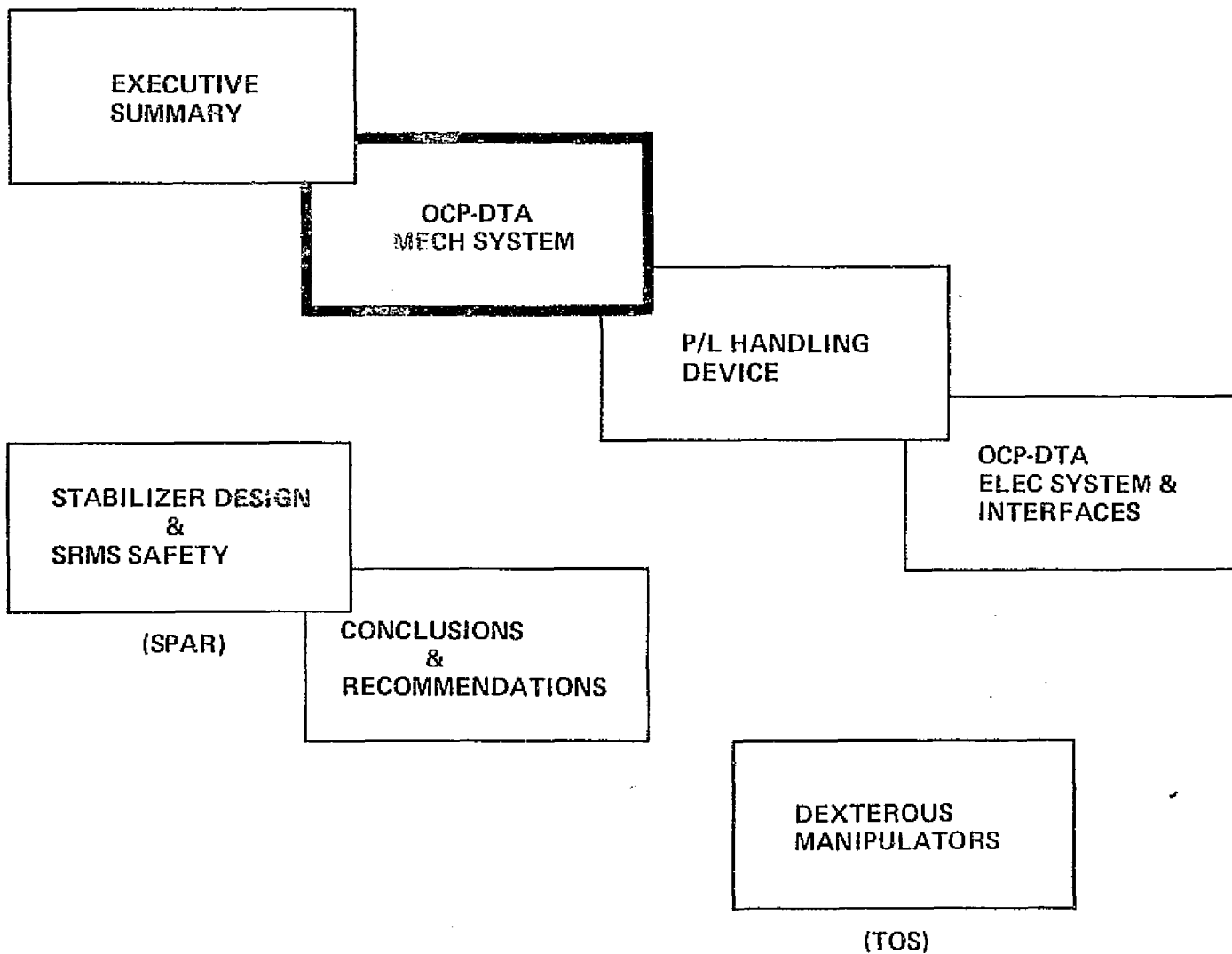
The pros and cons of buying an off-the-shelf manipulator or designing a new manipulator for the OCP stabilizer during development testing is summarized on the facing page. Available commercial manipulators used in "hot cells" are heavy and bulky, but do not provide the performance and flexibility at low cost, to evaluate the requirements for the OCP flight article. A new design would advance technology faster and provide a device whose weight, size and general performance would be more in-line with the ultimate flight article device.

The selection of the approaches discussed on the opposite page is mainly a budgetary and scheduling issue. The off-the-shelf device could be delivered within nine months at a cost that is within cost targets. A new device could be delivered in about 15 months at a cost above targets though costs could be budgeted over a two year period to minimize the budgetary impact.

STABILIZER – COMMERCIAL OR NEW BUILD

| | PROS | CONS |
|-------------|---|--|
| COMMERCIAL: | <ul style="list-style-type: none"> • MEETS PERFORMANCE AND FUNCTIONAL REQMTS AT LOW COST • THE NEED FOR A STABILIZER IS AT ISSUE – WHY PAY FOR A NEW DEVELOPMENT IF IT IS NOT NEEDED? | <ul style="list-style-type: none"> • NEEDS MODIFICATION TO OPERATE IN RESOLVED RATE MODE • NEEDS SOFTWARE PACKAGE • HEAVY & BULKY |
| NEW BUILD: | <ul style="list-style-type: none"> • WEIGHT & SIZE COMPATIBLE WITH SPACE VEHICLE • MORE RAPID DEVELOPMENT OF SPACE QUALIFIED STABILIZER FOR OCP IF STABILIZER IS NEEDED | <ul style="list-style-type: none"> • MAY EXCEED COST TARGETS |





PRESENTATION AGENDA

- DESIGN GROUND RULES
- DTA CONFIGURATION
- DTA DEPLOYED & STOWED FEATURES
- SIZING REQUIREMENTS & TRADES
- MATERIAL SELECTION

REPRODUCING THIS DOCUMENT IS NOT PERMITTED

DTA DESIGN GROUNDRULES

The DTA will be evaluated in a series of tests and simulations conducted at the Manipulator Development Facility. All DTA components must be designed for operation in this 1 g environment. As such, weight is not a design issue and emphasis is placed on designing a vehicle capable of low cost manufacturing, utilizing commercial grades of low cost, readily available materials. Because the established design safety margins are large, piece part inspection will be eliminated and only final inspection of the assembled vehicle will be performed. This procedure will significantly reduce manufacturing costs without compromising safety.

Further reduction of costs was realized by designing only those mechanisms that must be operated from the foot restraint platform to be compatible with EMU suited operations. Other operations such as the folding demonstration will utilize pip pins to provide positional locks.

To meet simulation objectives, a relatively inexpensive off-the-shelf commercial manipulator with 6 degrees of freedom is recommended for use as the DTA stabilizer.

DTA DESIGN GROUNDRULES

- **1 g ENVIRONMENT – WEIGHT NOT AN ISSUE**
- **LOW COST MANUFACTURING APPROACH AND MATERIALS SELECTION**
- **SELF-LOCKING MECHANISM FOR THOSE ELEMENTS INVOLVED WITH OPERATIONAL TASK**

(e.g., C&D CONSOLE POSITION FORE & AFT)

- **THOSE MECHANISMS ASSOCIATED WITH FOLDING DEMONSTRATION CAN USE PIP PINS**
- **INSPECTION OF ASSEMBLED ARTICLE IS SUFFICIENT**
- **DESIGN FOR INTERFACE WITH PAR 3000**



DTA DESIGN LOADS & CRITERIA

A chart listing the various design criteria and the rationale associated with the design loads is shown on the opposite page. Loads associated with operation transportation, handling, as well as stiffness, frequency response, and some readily identifiable failure loads are defined.

DTA – DESIGN LOADS & CRITERIA

| | | | | | | | |
|--|---|---------------------------------------|--------------|---------------------------------------|----------|------|--------------------------|
| TRANSPORTATION (PACKAGED) MIL-STD-810C | <div>A. <u>VIBRATION</u> RAIL, AIR, SEA, OR SEMI-TRAILER</div> <table><tr><td><u>FREQ</u></td><td><u>LEVEL</u></td><td><u>SINUSOIDAL CYCLING 84 MIN/AXIS</u></td></tr><tr><td>5-200 Hz</td><td>1.5g</td><td>SWEEP 5-200-5 IN 12 MIN.</td></tr></table> <div>B. <u>SHOCK</u> 20g – TERMINAL SAWTOOTH 11 MS PULSE IN EACH OF 3 AXIS</div> | <u>FREQ</u> | <u>LEVEL</u> | <u>SINUSOIDAL CYCLING 84 MIN/AXIS</u> | 5-200 Hz | 1.5g | SWEEP 5-200-5 IN 12 MIN. |
| <u>FREQ</u> | <u>LEVEL</u> | <u>SINUSOIDAL CYCLING 84 MIN/AXIS</u> | | | | | |
| 5-200 Hz | 1.5g | SWEEP 5-200-5 IN 12 MIN. | | | | | |
| HANDLING | <div>A. 1g STEADY STATE (GRAVITY)</div> <div>B. HOIST – 2g WITH DIRECTIONS UP TO 20° FROM LOCAL VERTICAL</div> | | | | | | |
| OPERATIONAL LIMITS LOADS | <div>A. <u>PLATFORM AND BASE MODULE ASSY</u> OPERATOR (200 LB + 175 LB (EMU) CAN APPLY SUDDEN LOAD (M.F. = 2) VERTICALLY WHILE STEPPING INTO PLACE.</div> <div>B. <u>HANDHOLDS</u> 187 LB IN ANY DIRECTION PER JSC-10615. OPERATOR CAN APPLY THIS LOAD TO CONSOLE, TOOL BOX AND STANCHIONS WITHIN HIS REACH.</div> <div>C. <u>FOOT RESTRAINT</u> 140 LB (ULT) IN TORSION PER JSC-10615</div> <div>D. <u>STABILIZER TIP FORCE</u> 150 LB IN ANY DIRECTION 400 IN.-LB TORSION</div> <div>E. <u>MFD RMS INTERFACE LOAD</u> THE RMS IS CAPABLE OF APPLYING A LOAD OR 50 LB IN ANY DIRECTION PER JSC-11029</div> | | | | | | |
| SUDDEN STOP | <div>A. <u>CONSOLE</u> THE CONSOLE SHALL WITHSTAND 3.7g ACTING ALONE, AND 1.4g WITH THE WEIGHT OF OPERATOR (200 + 175 = 375 LB) ALSO ACTING</div> <div>B. <u>TOOL BOX</u> THE STANCHIONS SHALL WITHSTAND 4.5g WITH THE TOOL BOX ACTING ALONG AND 2g WITH THE WEIGHT OF THE OPERATOR ALSO ACTING.</div> | | | | | | |
| STIFFNESS AND FREQUENCY REQUIREMENTS | <div>A. <u>CONSOLE</u> THE CONSOLE SHALL DEFLECT LESS THAN 0.2 INCHES UNDER A 60 LB LOAD.</div> <div>B. <u>OPERATOR</u> VERTICAL FREQUENCIES OF THE OPERATOR IN THE RANGE OF 4-8 Hz SHALL BE AVOIDED HORIZONTAL FREQUENCIES OF THE OPERATOR LESS THAN 2 Hz SHALL BE AVOIDED</div> | | | | | | |
| DROP TO OFF-LINE POSITION | <div>A. <u>CONSOLE</u> THE CONSOLE SHALL WITHSTAND 7.5g IF DROPPED TO THE OFF-LINE POSITION</div> <div>B. <u>TOOL BOX</u> THE TOOL BOX SHALL WITHSTAND 30g IF DROPPED TO THE OFF-LINE POSITION WHEN FULL AND 50g IF DROPPED TO THE OFF-LINE POSITION WHEN EMPTY.</div> | | | | | | |

GRUMMAN

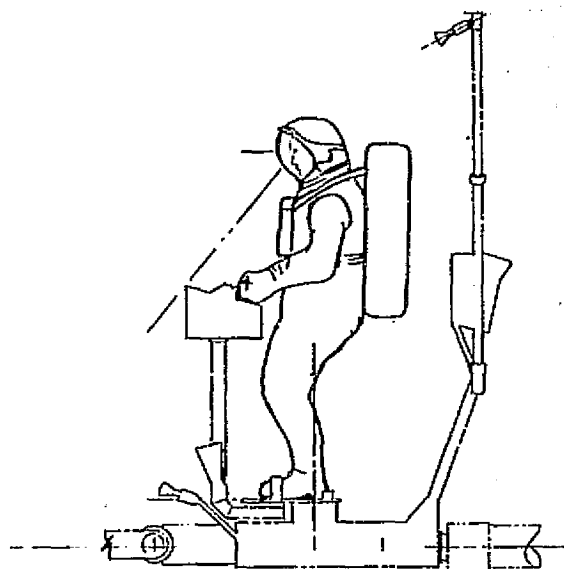
DTA SIZING REQUIREMENT

The design of the DTA has considered the range of sizes of operators from the 5th percentile female operator to the 95th percentile male operator. Where it was felt that a fixed location component could not satisfy the full range of operators, provision has been made to make those components adjustable. In the interest of cost savings, these adjustments have been made to be accomplished by a shop technician rather than providing for adjustment by a suited operator.

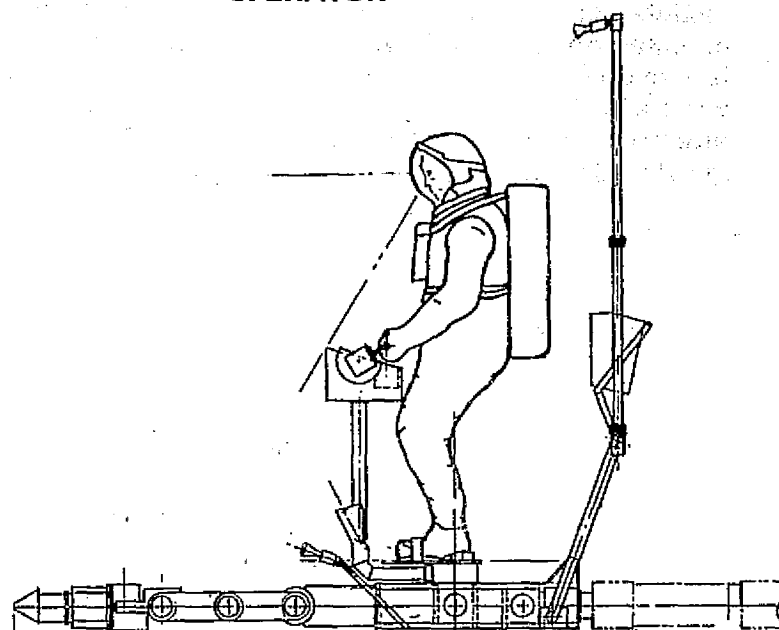
If after evaluation is completed a fixed position component is not suitable for the entire range of operators, the design of the flight article will be modified to incorporate an adjustment capable of operation by a suited astronaut.

DTA SIZING REQUIREMENT

5TH PERCENTILE FEMALE
OPERATOR



95TH PERCENTILE MALE
OPERATOR



ORIGINAL PAGE IS
OF POSTALITY

GRUMMAN

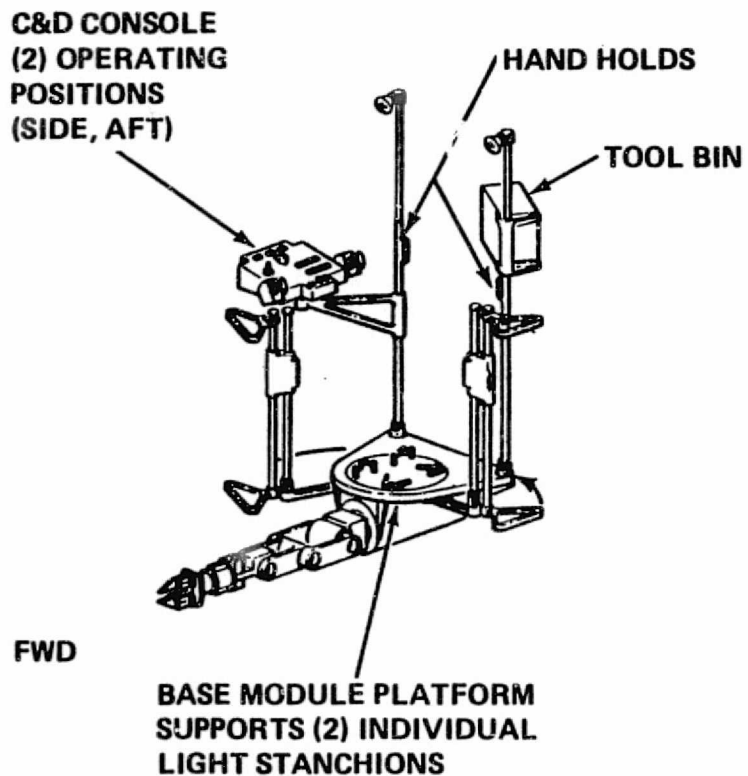
DTA CONFIGURATION DEVELOPMENT

The DTA configuration has been modified since the Mid-Term Review. At that time the configuration consisted of a large base module platform which supported two individual vertical light stanchions, adjustable vertically and in azimuth. The control console had two operating positions (aft and side) while the tool box was mounted to one of the light stanchions.

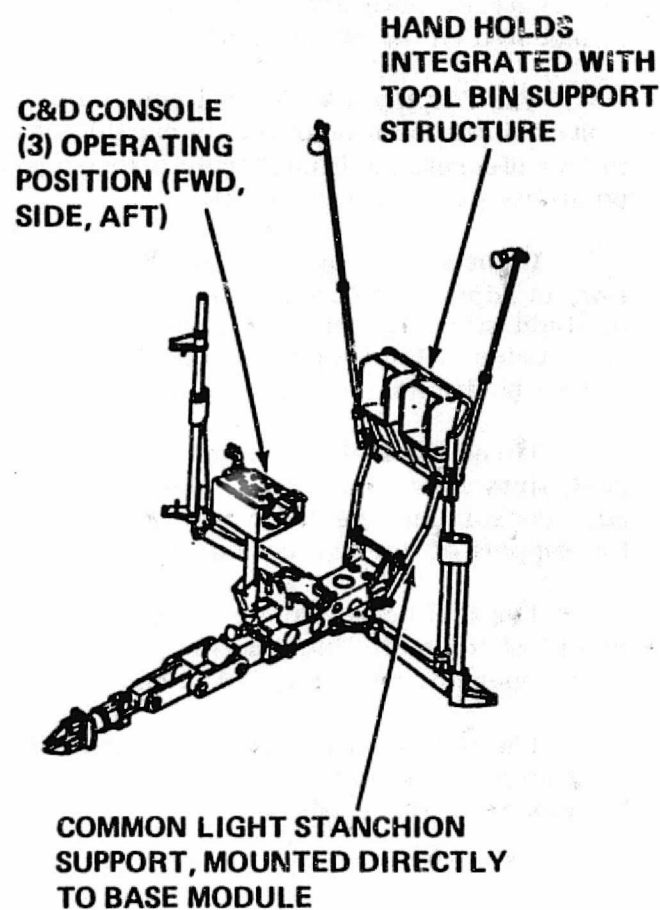
The configuration that has evolved is shown on the opposite page. The large base module platform was eliminated and a light system providing adjustment in all axes, mounted directly to the base module (strongback). The Displays and Controls console is mounted concentric with the foot restraint platform and provides three operating positions (forward, aft and side). The tool box has been divided into two sections and integrated with the hand-hold support structure. These changes provide the DTA with greater flexibility for evaluation of man/machine interfaces during the test phase.

DTA CONFIGURATION DEVELOPMENT

A. CONFIGURATION AT MID-TERM REVIEW



B. PRESENT CONFIG



ORIGINAL PAGE IS
OF POOR QUALITY

OCP-DTA GENERAL ARRANGEMENT

The figure on the opposite page depicts the OCP DTA configuration selected for fabrication and test. It consists of a base module or strongback sized to interface with the PAR 3000 stabilizer and the Manipulator Development Facility arm. A NASA supplied (GFE) foot restraint platform configuration capable of 360° rotation with a lock position every 45° , is mounted on the strongback.

The Display and Control console pivot is mounted concentrically with the foot restraint platform pivot and is capable of being rotated independently of the platform to five discrete positions; from forward to aft in 45° increments with three operating positions (fwd, side, and aft).

Lighting is provided with three flood lights. One light fixture mounted forward and low, is adjustable in azimuth and elevation. The two remaining lights are mounted to the light stanchion which in turn is mounted aft on the base module. The stanchion consists of a series of telescoping tubes which provide light fixture adjustment in height, width fore and aft positions, as well as azimuth and elevation.

Three handholds are provided to aid the EMU suited operator to ingress/egress the foot restraints as well as assisting him in rotating the foot restraint platform. One is located in the D&C console and the other two are built off the light stanchion and provide the structural frame for support of the two tool boxes.

The tool boxes can provide storage for both small and medium sized tools. The boxes can pivot to an off-line position (compatible with storage) to provide increased visibility to the operator when the C&D console is placed in the aft operating position.

The DTA configuration provides a 48 inch clear cylindrical envelope (C&D console off-line position) to permit freedom of movement for a EMU suited operator standing on the foot restraint platform.

OCP FOLDING SEQUENCE

The opposite page illustrations indicate the folding sequence of the OCP from the fully deployed position to the fully folded configuration ready for re-stowage in the shuttle bay.

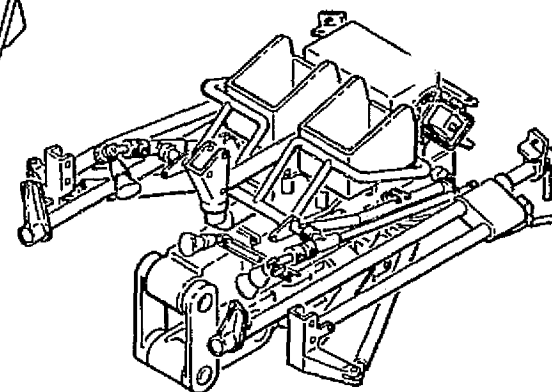
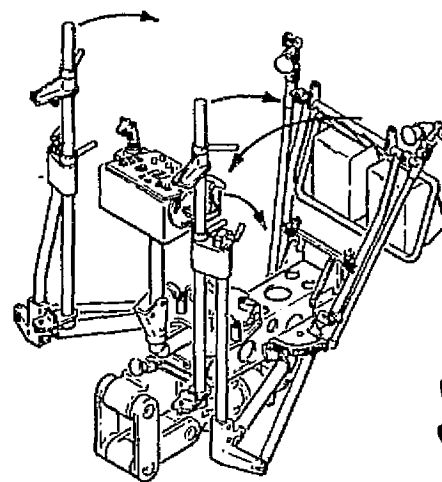
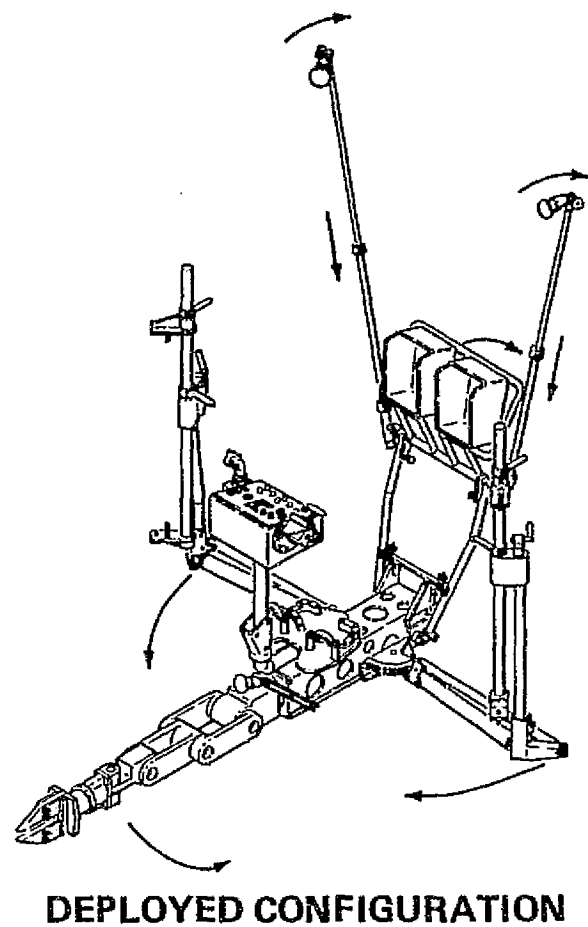
After a mission has been completed and while the OCP is still attached to the shuttle remote manipulation system, the operator starts the folding sequence while still standing on the foot restraint platform.

1. A typical sequence of operation follows:

Operator using the D&C console lowers the PAR 3000 stabilizer to its stowed position under the strongback

2. The Operator lowers the lights on the telescoping tubes to their minimum height, rotates them to line up with the lower support frame and then telescopes them in to their minimum width
3. Operator lowers tool boxes from their upright positions to the off-line positions
4. Operator rotates payload landing device to forward position and then folds them down to their stowed position
5. Operator now rotates foot restraint platform to forward position and detaches himself from the OCP
6. The light support frame is now lowered forward to its stowed position over the foot restraint platform
7. The D&C console is now unlocked, folded aft and latched in its stowed position, trapping the light stanchion support frame and the tool boxes
8. The entire OCP is now ready to be placed in its stowage brackets in the shuttle bay.

OPEN CHERRY PICKER FOLDING SEQUENCE

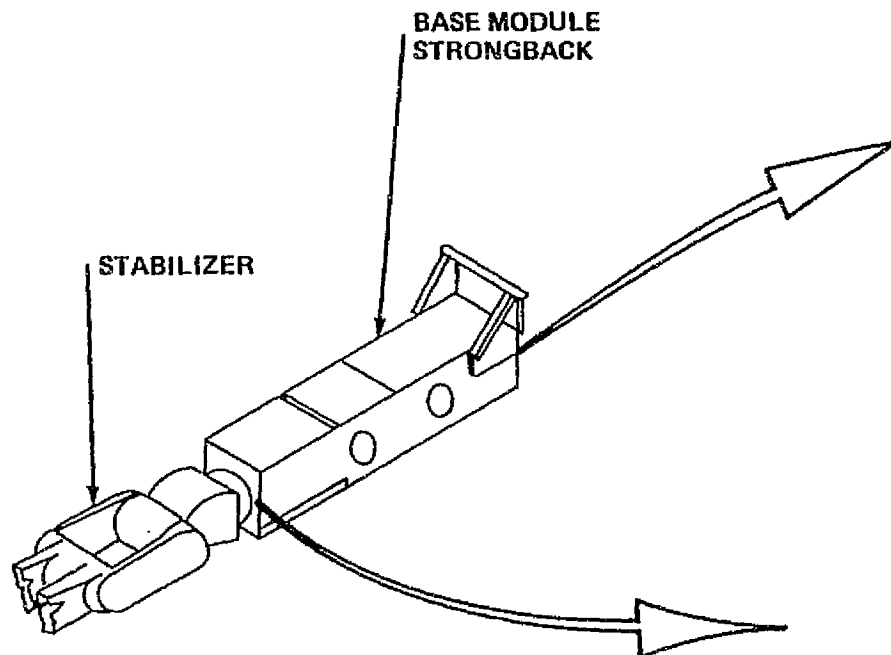


ORIGINAL PAGE IS
OF POOR QUALITY

END BULKHEADS FOR STABILIZER AND MDF ARM ATTACHMENT

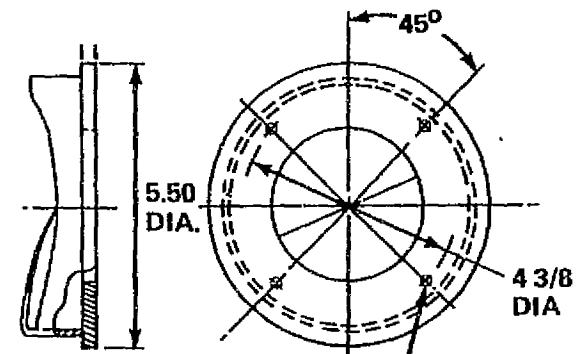
The opposite page illustration of the DTA Base Module (strongback) identifies the interfaces with the MDF arm and the PAR 3000 stabilizer and the loads required to be supported at these interfaces. Based on these requirements, a strongback cross-section of 8 x 8 inches was established.

END BULKHEADS FOR STABILIZER & MDF-ARM ATTACHMENT

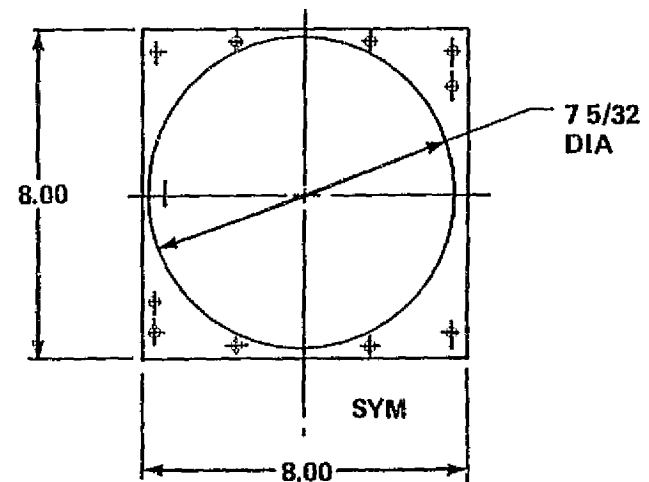


SIZING REQUIREMENTS

- MDF-ARM ATTACHMENT
50 LB LOAD APPLIED ANY DIRECTION
- STABILIZER TIP LOAD 150 LB
ANY DIRECTION, 400 IN.-LB TORSION



THD FOR 1/4-28 UNF-28
HELICAL COIL INSERT
(NOTE: WILL BE CHANGED TO SNARE
FIXTURE INTERFACE)
MDF-ARM INTERFACE



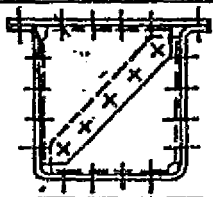
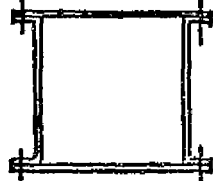
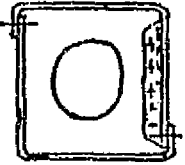
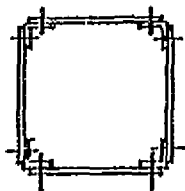
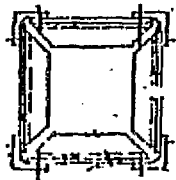
STABILIZER INTERFACE



BASE MODULE STRUCTURAL CONFIGURATION TRADEOFF

The table on the opposite page defines five different configurations proposed for the structure of the base module (strongback). While each configuration has merits, Configuration C was selected because it is easily brake-formed without the use of special tools and requires less assembly time to fabricate the finished assembly. Its disadvantage is that the finished product is not symmetrical externally, but this presents no real problem as the number of side-mounted components is very small.

BASE MODULE STRUCTURAL CONFIGURATION TRADEOFF

| | | DESCRIPTION | PROS | CONS |
|------------------|---|--|--|--|
| A) |  | HAT SECTION & COVER PLATE | FEW DETAIL PARTS LESS ASSEMBLY TIME | DIFFICULT BRAKE FORMING |
| B) |  | BACK-TO-BACK CHANNELS & PLATES (2) | SIMPLE BRAKE FORMED PARTS | EXCESSIVE ASSEMBLY TIME |
| ✓ C) SELECTED |  | BENT-UP PLATES (2) | SIMPLE BRAKE FORMED PARTS – LESS ASSEMBLY TIME | SPECIAL TREATMENT RE- QUIRED FOR ATTACHING L&R HAND ADD ON PARTS |
| D) |  | CORNER ANGLES & PLATES | SIMPLE EXTRUDED SECTION | EXCESSIVE ASSEMBLY TIME |
| E) |  | EXTERNAL ANGLES & PLATES | SIMPLE EXTRUDED SECTIONS | COMPLEX & EXCESSIVE ASSEMBLY TIME |

GRUMMAN

DTA FOOT RESTRAINT AND C&D CONSOLE ATTACHMENT TO BASE MODULE

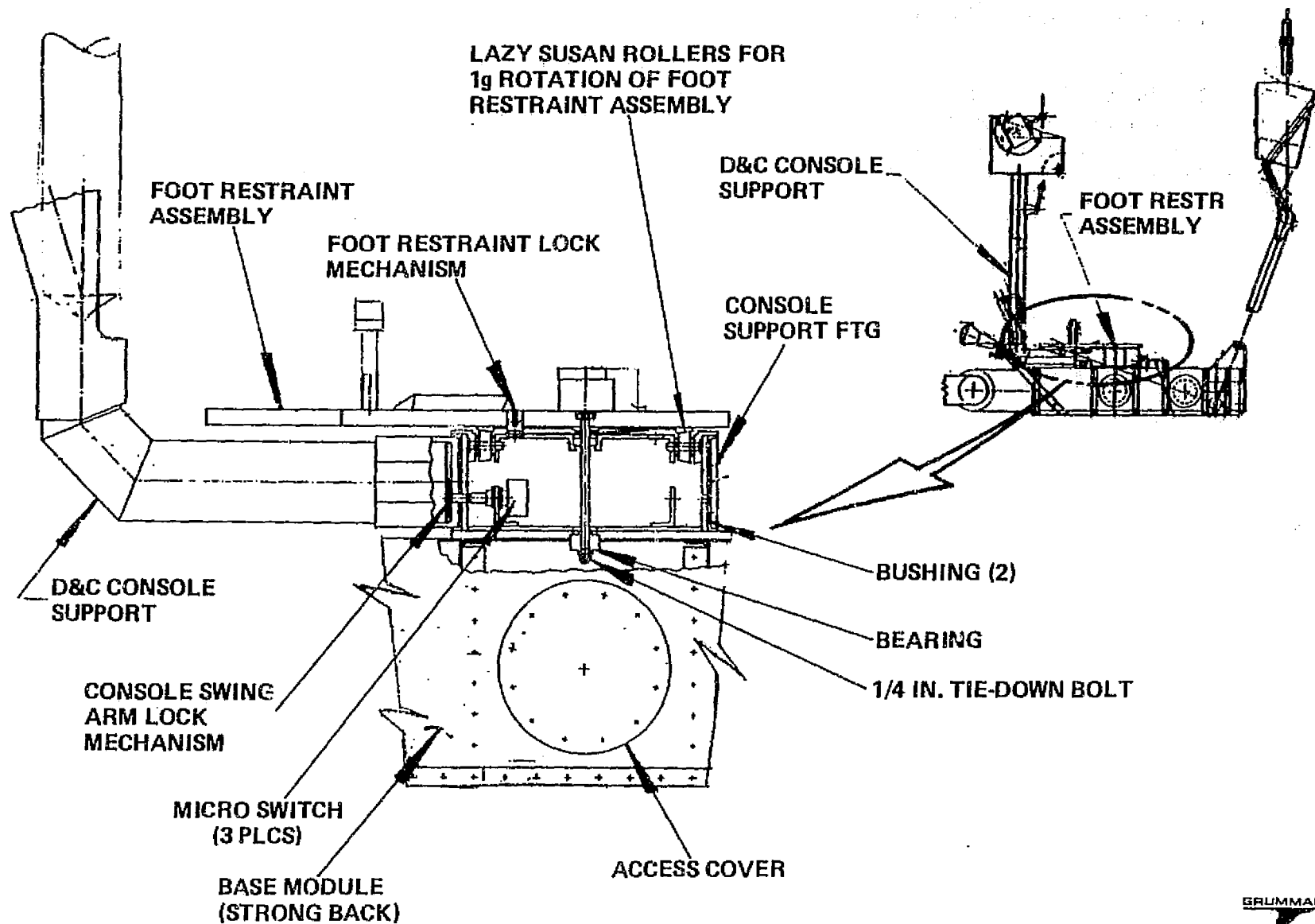
The DTA utilizes a modified Shuttle-type foot restraint system. The shuttle foot restraint is designed for operation in a zero g environment and the rotating mechanism was considered unsatisfactory for the 1 g test environment the DTA operator works in. For this reason, a lazy susan roller system capable of handling the 1 g loads in an easily rotatable platform arrangement was substituted for the shuttle platform design. The platform-mounted foot restraint fittings (heel & toe) which interface with the EMU boots are NASA supplied (GFE). A platform latch system actuated by a lanyard provides a latch position every 45° for the entire 360° of platform rotation and can be operated independently of the position or rotation of the C&D console support.

The C&D console support is mounted around the same shaft that supports the foot restraint platform and has five latched positions from forward to aft.

Three console operating positions are provided (forward, side, and aft) and at each of these positions the lock mechanism activates a micro-switch that inputs to the facility computer to change the control axis to match the C&D console position.

The foot restraint platform and the C&D console are attached to the base module (strongback) by one $\frac{1}{4}$ -inch diameter bolt that is accessible through an access cover in the side of the strongback.

DTA FOOT RESTRAINT & D&C CONSOLE ATTACHMENT TO BASE MODULE



GRUMMAN

DTA TOOL BIN STOWAGE ARRANGEMENT

The illustration on the opposite page depicts a possible arrangement of tools in the two tool boxes supplied with the OCP-DTA. Each tool box is 9.5" x 9.9" x 13.5" providing a total volume of 1.25 ft³.

One tool box is shown arranged with Skylab-type pullout drawers and is capable of holding small tools typically required for general work. The other box is shown holding a medium sized tool which may or may not be mission peculiar. In the event of a mission requiring a significant number of mission peculiar medium size tools, a special tool box can be designed for that mission and readily installed to replace the present box shown.

The maximum combined weight of tools presently planned for is 50 lb.

DTA TOOL BIN STOWAGE ARRANGEMENT

LARGE HAND TOOL STORAGE
(REF DOUBLE PRONG CLAW)

SKYLAB TYPE PULLOUT
TOOL DRAWS

HAND HOLD

NOTE

- 1) MAX WT OF TOOLS = 50 LB
- 2) TOOL LIST TBD

ORIGINAL PAGE IS
A PENDING

GRUMMAN

CANDIDATE TOOLS FOR OCP SERVICING & MAINTENANCE MISSIONS

The table shown on the opposite page lists some of the EVA hand tools in each of the size categories that may be carried on the OCP for servicing and maintenance missions. The lists were obtained from Johnson Space Center "Shuttle EVA Description & Design Criteria" document JSC-10615, and AIAA paper #72-230 Space Tools and Support Equipment.

CANDIDATE TOOLS FOR OCP SERVICING & MAINTENANCE MISSIONS

| SMALL | | MEDIUM | | LARGE | |
|------------------------|----------|-----------------------------------|----------|---------------------------|----------|
| ITEM | WT | ITEM | WT | ITEM | WT |
| 1. RATCHET WRENCH | TBD ↓ | 1. PINCH BAR | TBD ↓ | 1. CABLE CUTTER | TBD ↓ |
| 2. UNIVERSAL JOINT | | 2. ADJUSTABLE WRENCH | | 2. SHEARS | |
| 3. SPINNER | | 3. PRONG TOOL | | 3. SHEPHERD'S HOOK | |
| 4. RATCHET EXTENSION | | 4. BOLT INSTL (BIRT) | | 4. SPACE IMPACT TOOL | |
| 5. SOCKET SET | | 5. INERTIA WHEEL | | 5. SPIN TORQUE SPACE TOOL | |
| 6. ADAPTER | | 6. SPACE POWER TOOL | | | |
| 7. SCREW DRIVER | | 7. SPACE TOOL MITTEN | | | |
| 8. TORQUE WRENCH | | 8. MMS-S/S MODULE RELEASE TOOL | | | |
| 9. PLIERS | | | | | |
| 10. HAMMER - BALL PEEN | | | | | |
| 11. SCISSORS | | | | | |
| 12. TIN SNIPS | | | | | |
| 13. DIAGONAL CUTTERS | | | | | |

REF: 1 - JSC-10605 - "SHUTTLE EVA DESCRIPTION ON & DESIGN CRITERIA

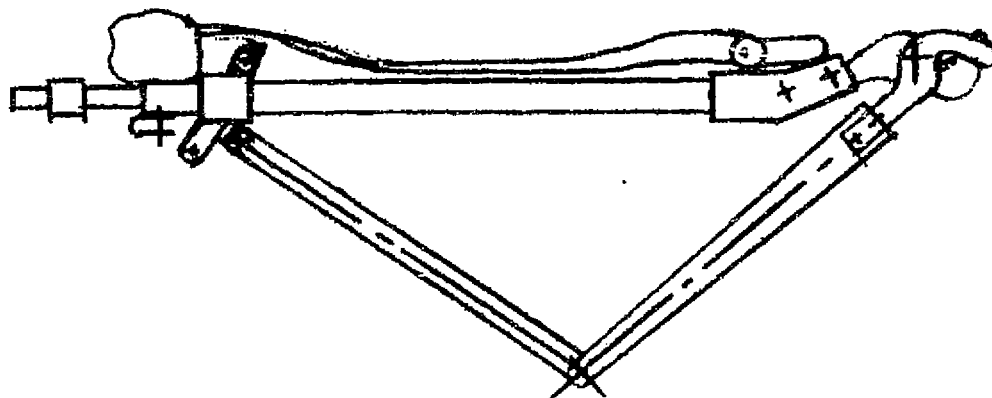
2 - AIAA PAPER #72-230 - "SPACE TOOLS AND SUPPORT EQUIPMENT - CURRENT TECHNOLOGY AND FUTURE REQUIREMENTS."

BRUMMAN
↓

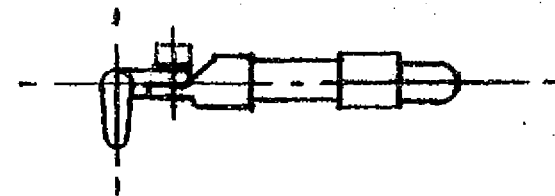
LARGE MISSION PECULIAR TOOLS

The opposite page figure defines some large mission peculiar tools that have been designed and used in past Skylab missions. These tools may be considered candidates for use on various OCP servicing and maintenance missions.

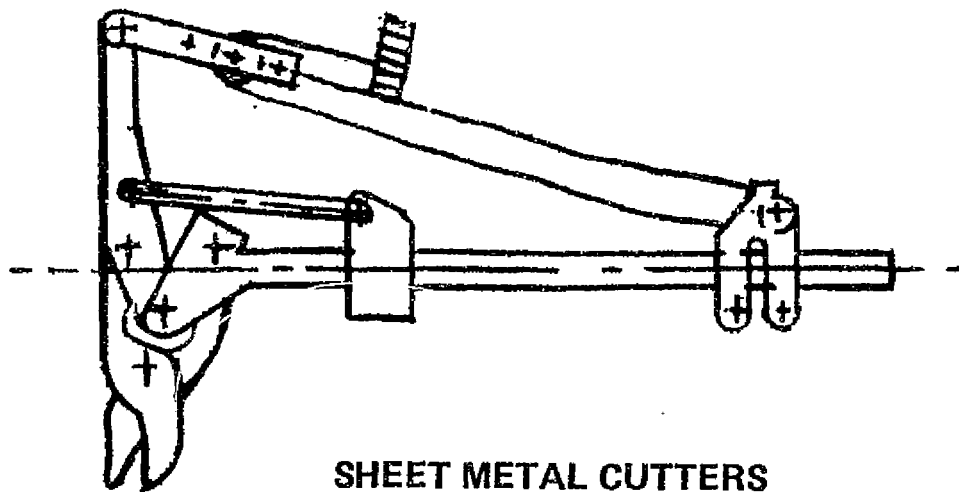
LARGE MISSION PECULIAR TOOLS



CABLE CUTTERS



DOUBLE PRONG CLAW



SHEET METAL CUTTERS

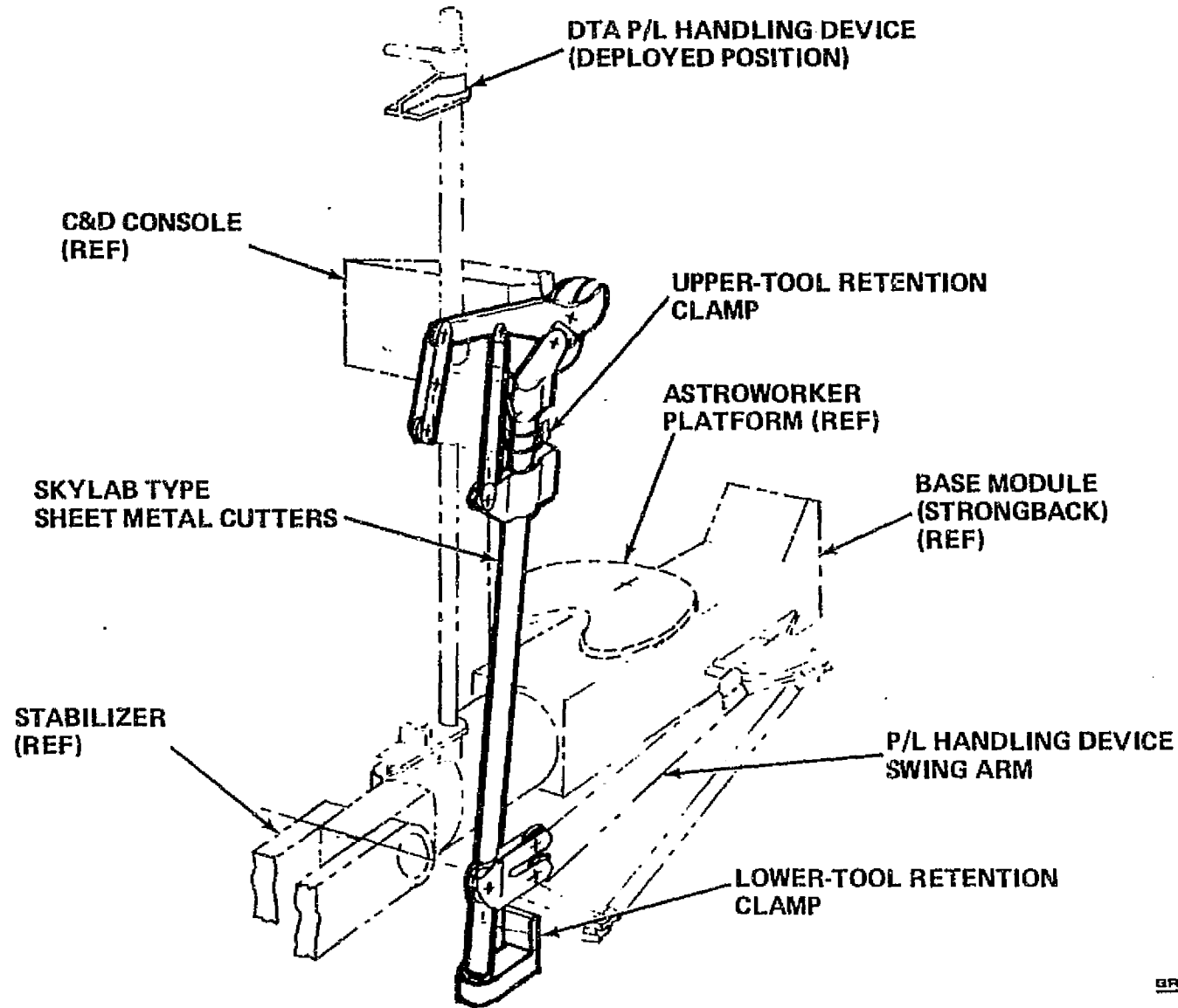
REF: JSC-10615 — SHUTTLE EVA DESCRIPTION &
DESIGN CRITERIA



OCP-DTA LARGE MISSION PECULIAR TOOL STOWAGE

A proposed method of storing one of the large mission peculiar tools on the OCP payload handling device is shown. This approach can be applied to any of the large tools previously shown on tools that will be developed to fill a future need.

OCP — DTA LARGE MISSION PECULIAR TOOL STOWAGE



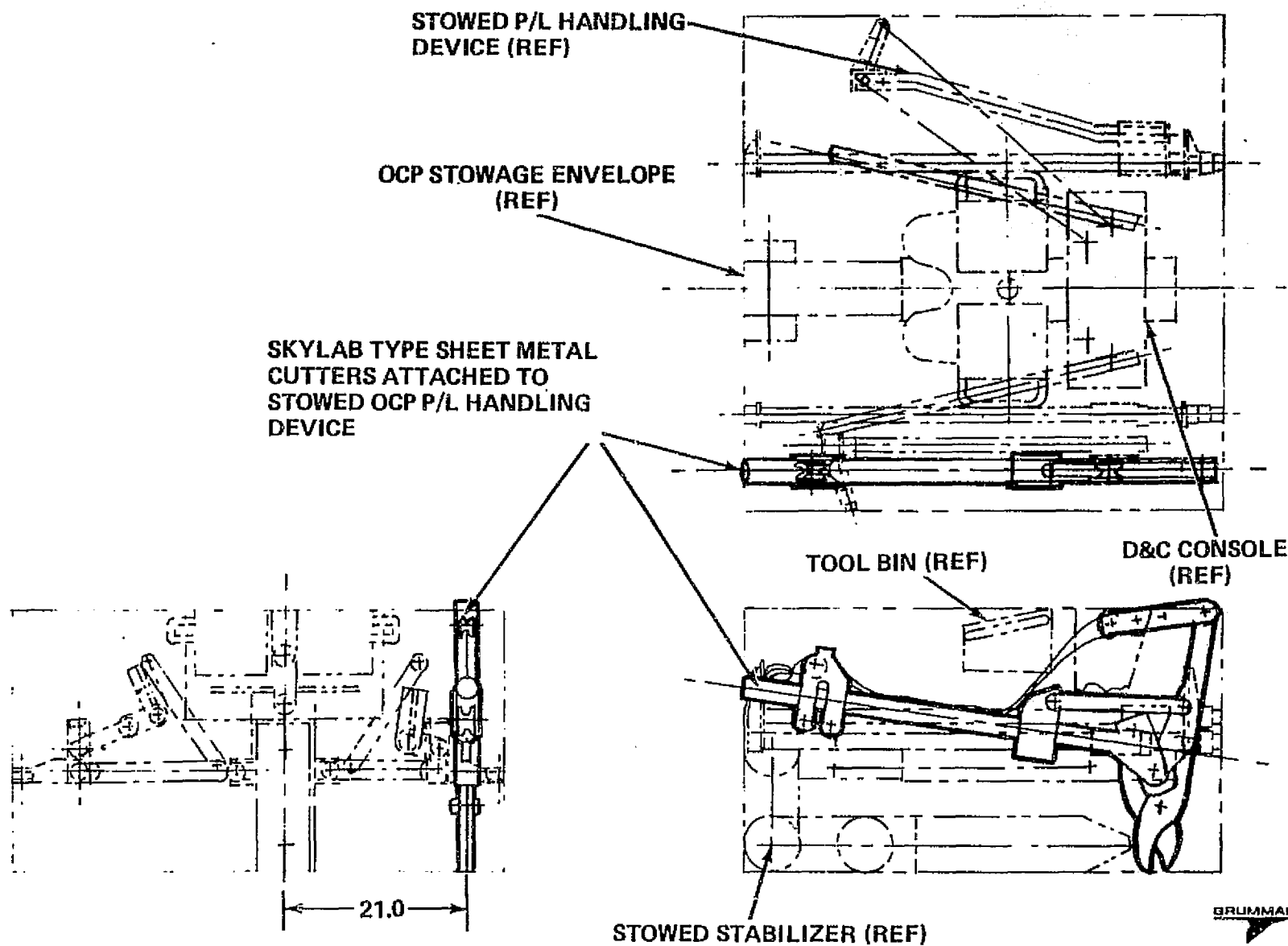
ORIGINAL PAGE IS
OF POOR QUALITY

GRUMMAN

LARGE MISSION PECULIAR TOOL STOWAGE ON OCP

The opposite page figure shows how the largest of the identifiable large tools would fit into the existing OCP stowage envelope without impacting the existing envelope. Other tools not shown would likewise be adaptable to mounting on the OCP and stowing within the existing stowage envelope.

LARGE MISSION PECULIAR TOOL STOWAGE ON OCP



ORIGINAL PAGE IS
OF POOR QUALITY

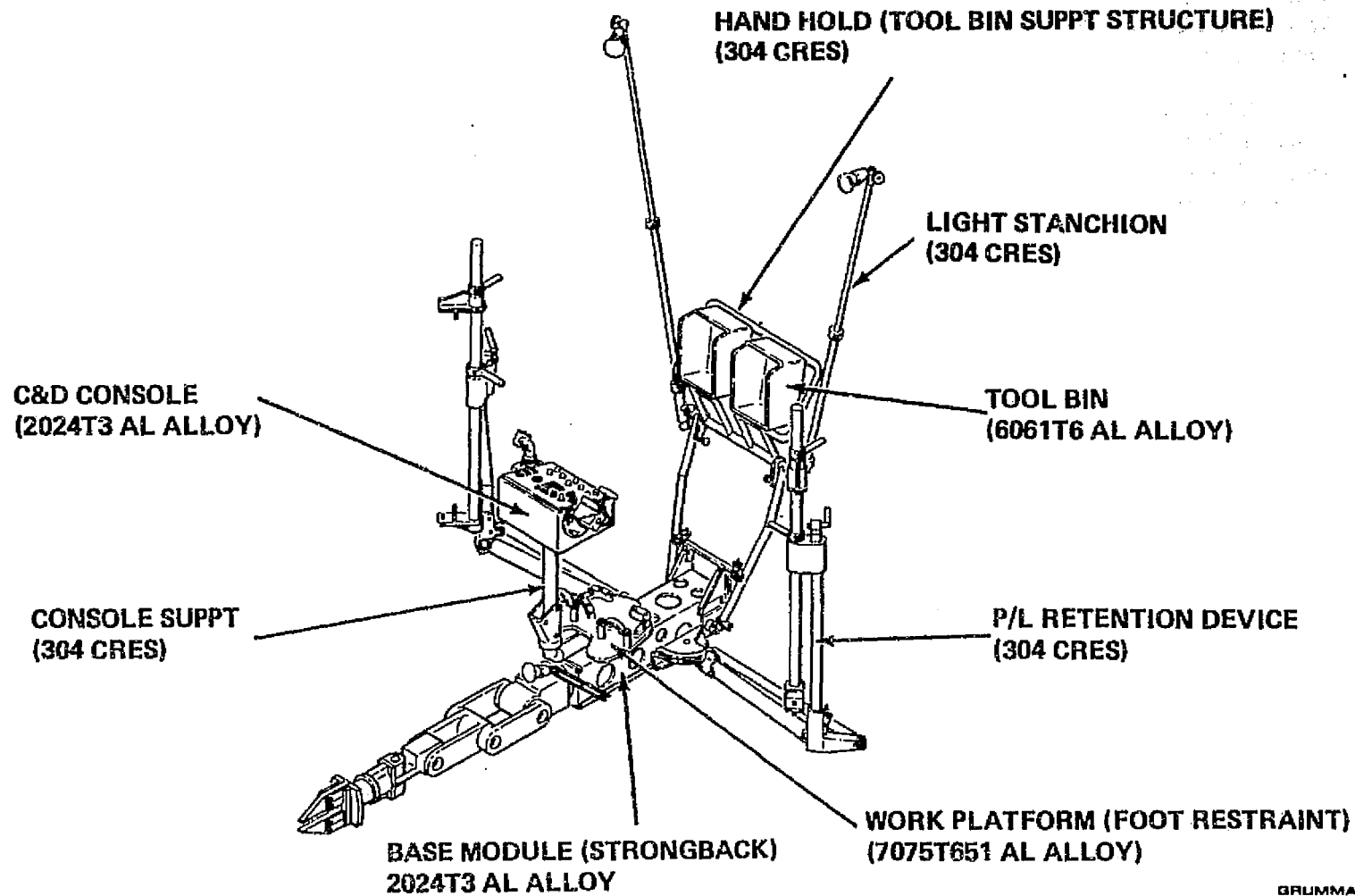
DTA MATERIAL SELECTION

The design of the DTA has been made using material that is inexpensive, readily available and capable of low cost manufacturing processes. While the end product is not therefore of minimum weight, that was not a design requirement.

The selection of materials was based on such factors as:

- Minimum-maximum material here at Grumman - 7075-76 PLATE 2024-T3 SHEET
- Commercially available, with short lead time - 300 series stainless tubing
- Weldability - 300 series stainless & 6061 ALUM
- Readily machinable - 7075-76 and 2024-T3
- Usable without further heat treatment after fabrication.

DTA MATERIAL SELECTION



ORIGINAL PAGE IS
OF 2000 QUALITY

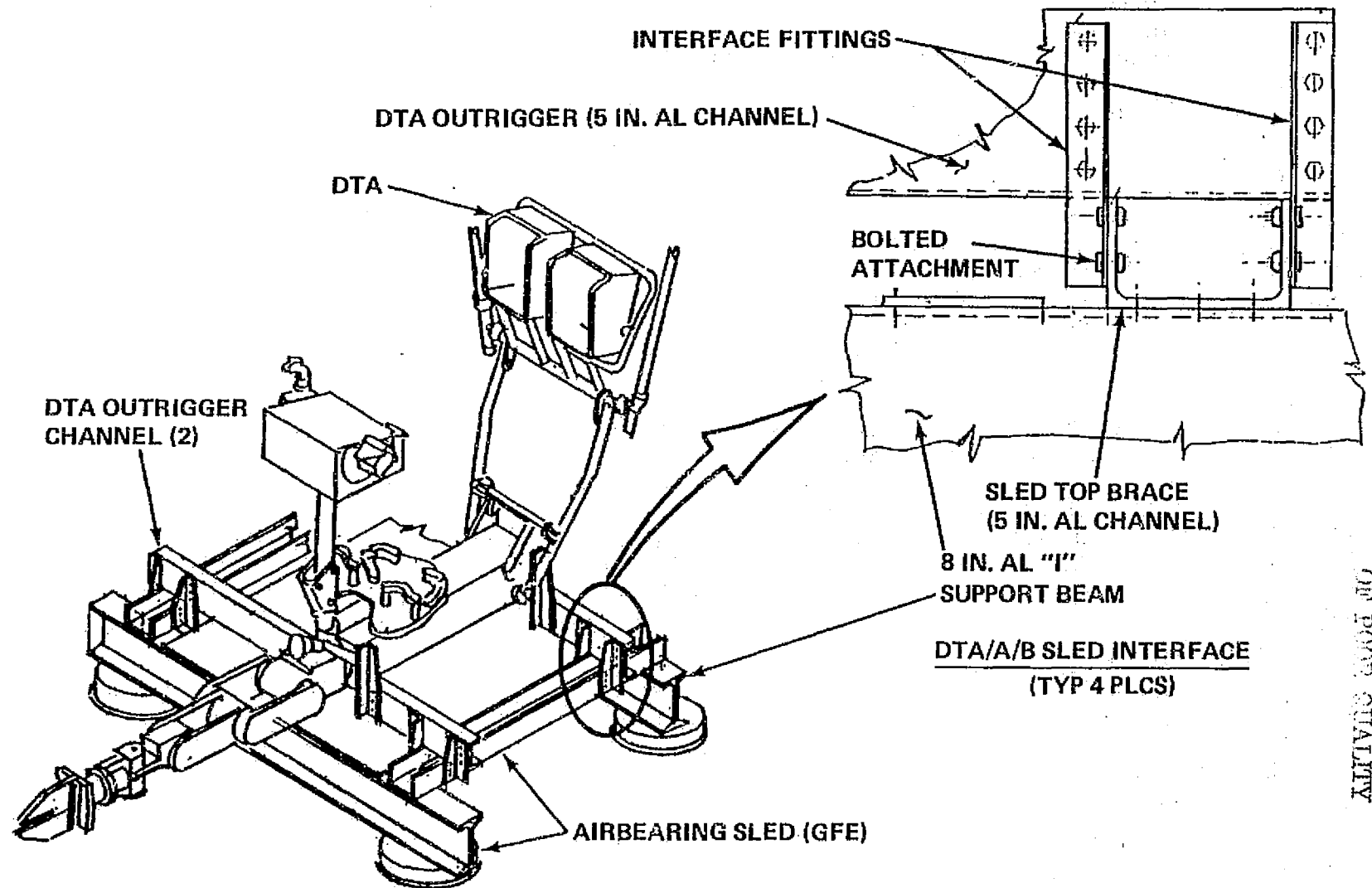


DTA AIR BEARING SLED STRUCTURAL INTERFACE

A DTA/Air Bearing Sled arrangement is shown on the opposite page. Two 5 inch deep x 36 inch long aluminum channel outriggers are attached to the forward and aft ends of the base module. These outriggers are used to span and attach to the two top braces of the air bearing sled. The bottled attachment is typical at four locations.

This arrangement places the DTA operator approximately $2\frac{1}{2}$ feet above the air bearing floor and provides an overall operating envelope of 10 ft x 3 ft x 11 ft. The DTA is positioned on the A/B sled to allow clearance for the 22 inch diameter capture envelope required for the automatic mating of the MDF arm shuttle snare-type end effector.

DTA/AIR BEARING SLED STRUCTURAL INTERFACE



ORIGINAL PAGE IS
OF POOR QUALITY

GRUMMAN

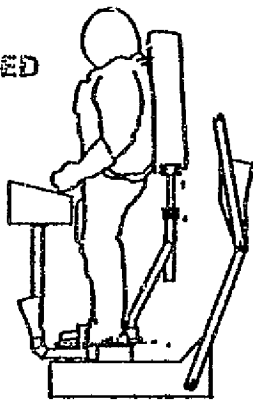
DTA SAFETY/REST RESTRAINT CONCEPTS

During testing of the DTA at velocities up to two feet per second with a EMU suited operator standing on the foot restraint platform, it is possible that the operator may be injured in the event of a sudden stop. To protect the operator and reduce his fatigue during the test sessions in the 1 g environment, several restraint concepts were defined.

- The overhead support concept is mounted to the air bearing sled and the inertia reel cable interfaces with the EMU PLSS. This system has no impact on DTA design but requires a bulky overhead structure that can limit task evaluations.
- The seat restraint concept provides good support of operator tasks. The seat mounted to a spring-loaded cylinder readily provides adjustment for the various percentile operators. This system requires an interface with the EMU and the foot restraint platform. When the operator has ingressed the foot restraints, a technicians assistance is required to make final adjustment of the restraint; once this is accomplished, the operators feet are trapped on the platform requiring a technicians assistance for him to egress the foot restraints.
- The back rest restraint concept (selected) protects and provides the support to reduce operator fatigue. The restraint is easily adjusted to accommodate the various percentile operators and does not interfere with the operators ingress/egress of the platforms foot restraints. In addition the restraint is readily detachable from the platform when the DTA has stopped moving. The restraint requires an interface with the operators PLSS and a modification of the foot restraint platform to accommodate the increased loading conditions.

SAFETY/REST RESTRAINT CONCEPT

✓
SELECTED

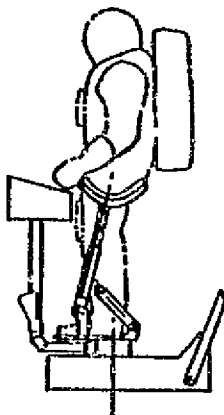


PRO:

- COMPACT
- REQD NO INTERFACE WITH SUIT
- READILY ADJUSTABLE
- EASY INGRESS/EGRESS
- ROTATES WITH PLATFORM

CON:

- PLATFORM MOD REQUIRED
- MAY BE RESTRICTIVE FOR SOME OPERATOR TASKS

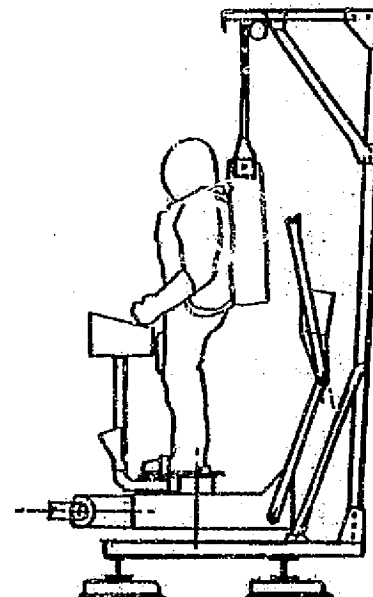


PRO:

- COMPACT
- ROTATES WITH PLATFORM
- GOOD SUPPORT OF OPERATOR TASKS
- READILY ADJUSTABLE

CON:

- PLATFORM MOD REQUIRED
- DIFFICULTY IN INGRESSING FOOT RESTRAINTS
- TRAP OPERATOR IN FOOT RESTRAINTS
- SEATS MAY NEED TAILORING FOR DIFFERENT PERCENTILE OPERATORS



PRO:

- REQUIRES NO MOD OF DTA
- READILY ADJUSTABLE

CON:

- BULKY CONFIGURATION
- CAN LIMIT SOME TASK EVALUATIONS

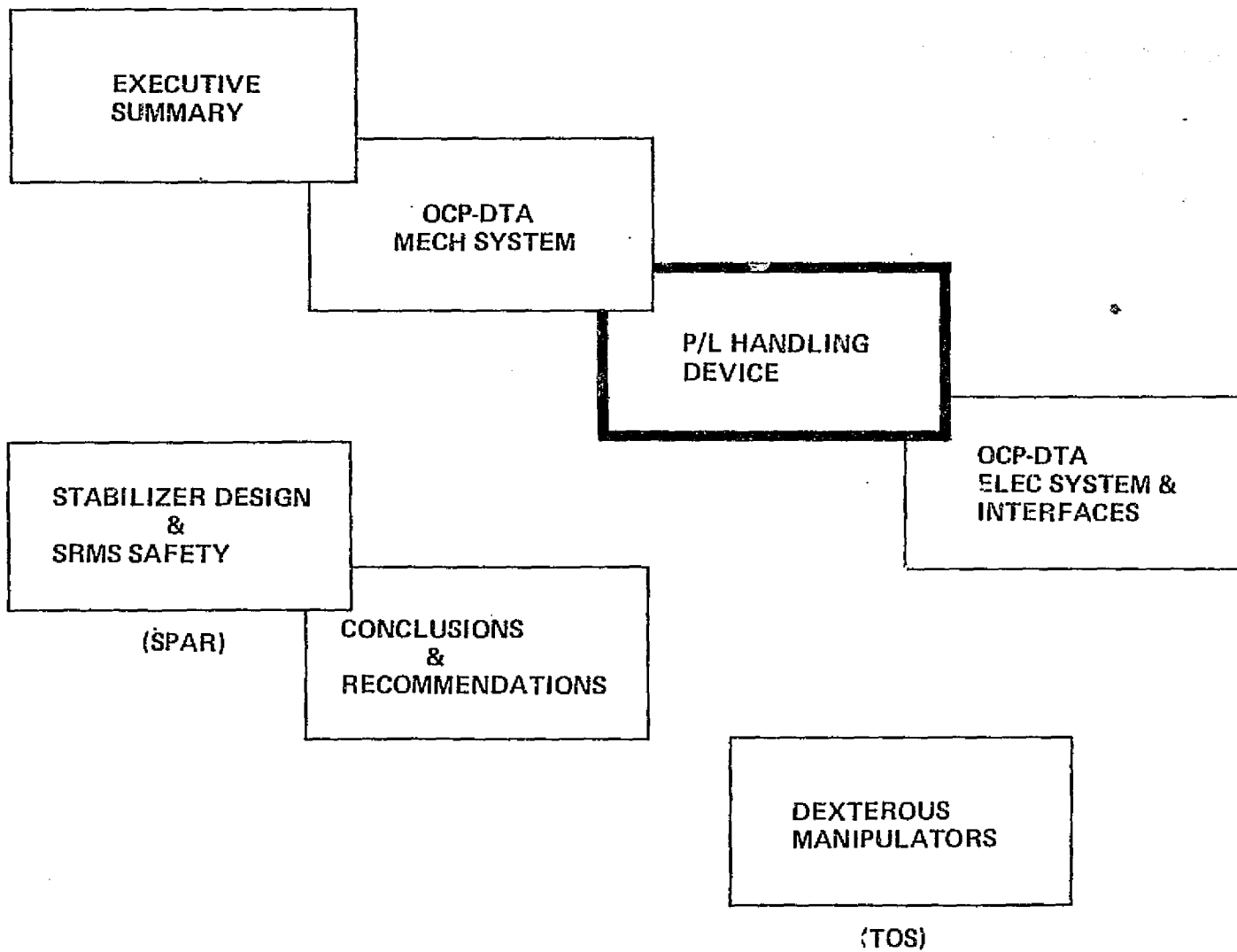
GRUMMAN

CONCLUSION

THE DEVELOPMENT TEST ARTICLE STRUCTURAL/ MECHANICAL CONFIGURATION DEFINED ON THE PRECEEDING PAGES HAS THE CHARACTERISTICS NECESSARY TO OPTIMIZE THE FOLLOWING PARAMETERS FOR A FLIGHT OCP:

- C&D CONSOLE HEIGHT, AND LOCATION
- LIGHT LOCATION & INTENSITY
- TOOL BOX SIZE AND ARRANGEMENT
- PAYLOAD HANDLING
- FOOT RESTRAINT PLATFORM SWIVELING
- OPERATIONAL TIME FOR THE PERFORMANCE OF TASKS
- OPERATOR VISIBILITY DURING TRANSIT & P/L HANDLING
- OPERATOR INGRESS/EGRESS





GRUMMAN

PAYLOAD HANDLING DEVICE

OBJECTIVE:

The design of the payload handling device (PHD) is conceived to be capable of assisting the EVA crewperson in the removal and stowage aboard the OCP, and replacement of payloads from a variety of satellites; i.e., MMS, LDEF, LST, and others.

The design for the development test article (DTA) should incorporate as many potential degrees-of-freedom and adjustments as possible to permit an extreme range of evaluation capabilities. This infers the use of a simple modular concept which can be easily changed.

The following data outlines the program that developed the datum concept.

OBJECTIVE

- **DEVELOP PAYLOAD HANDLING DEVICE TO:**
 - **ASSIST EVA ASTRONAUTS ABOARD OCP TO REMOVE, STOW, REPLACE PAYLOADS**
 - **BE COMPATIBLE WITH PAYLOADS ABOARD MMS, LDEF, AND OTHER TBD SATELLITES**
 - **INCORPORATE MULTI DEGREES-OF-FREEDOM AND ADJUSTMENT TO SUPPORT ADTA EVALUATION**



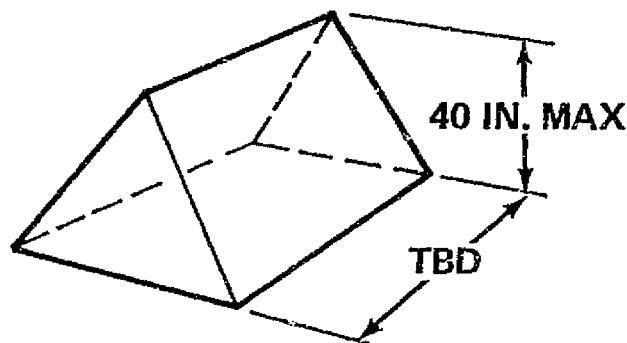
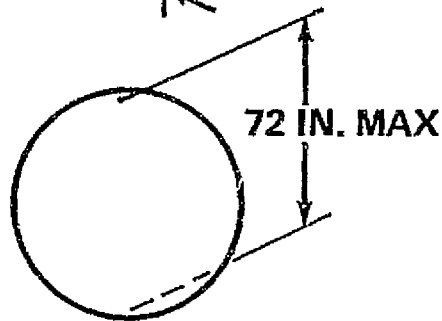
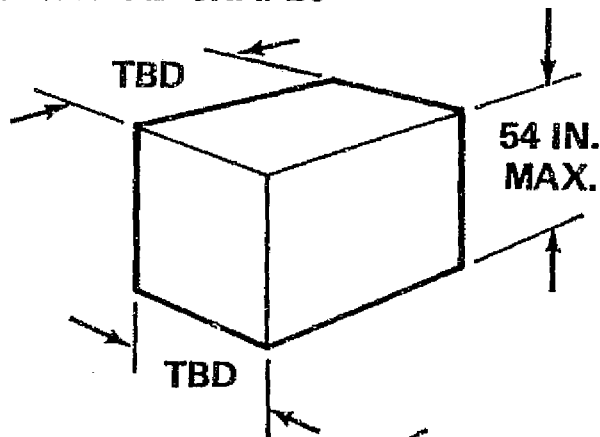
REQUIREMENTS

The following datum requirements have been established to support the DTA with consideration toward a flight article.

- Handle the three generic shapes and applicable sizes, as shown on the facing page, to cover the spectrum of anticipated payloads
- Handle a maximum weight of 50 lb to accommodate the potential weight of simulated payloads
- Resist manhandling forces of up to 187 lb that may be inadvertently applied by personnel at the DTA site.
- The person/mechanism interface shall consider the clearances required, the vision needed, the reach available, and the articulation required to permit an EVA suited crewperson to perform the established payload interchange
- Articulation movements for handling the payload and folding for stowage shall clear the (OCP) strongback, console, stabilizer, and lights/tool box.
- Stowage of the PHD shall be as compact as possible to minimize the volume used in the shuttle cargo bay.

REQUIREMENTS

PAYLOAD SHAPES



OBJECT WEIGHT

- 50 LB MAX

STRENGTH

- TO RESIST MANHANDLING FORCE OF 187 LB

MAN/MECHANISM INTERFACE

- PAYLOAD INTERCHANGE BY EVA SUITED ASTRONAUT

- CLEARANCES
- VISION

- REACH
- ARTICULATION

ARTICULATION

- INTERFACE WITH OCP

- STRONGBACK
- CONSOLE

- LIGHTS/TOOL BOX
- STABILIZER

STOWAGE

- COMPACT FOR SHUTTLE BAY



DESIGN CONSTRAINTS

The facing page identifies the following major design constraints that were used for the development of the datum payload handling device.

The astronaut's reach envelope dictates the location of controls and objects, relative to a stationary operator, that must be reached to perform the mission requirements.

The astronaut's pivot axis location constrains the radial reach envelope sweep to dictate the total available work area.

The stabilizer grip envelope must satisfy the ability to grapple a variety of shuttle cargo bay satellite berthing devices.

The multimission modular spacecraft (MMS) subsystem module handling tool, supplied by NASA, dictates the maximum distance the astronaut can be from the MMS to engage the tool in the module payload, operate the tool for release of the payload, and then position the payload for replacement of another one.

Payload removal clearances are required to provide an unobstructed removal of the payload. The clearances are dependent on the payload shape, size, and mounting provisions.

The OCP and applicable satellite structure impact the available space for the design of a payload handling device based on the required relationship of the astroworker to handle the specific payload.

DESIGN CONSTRAINTS

- ASTRONAUT'S REACH ENVELOPE
- ASTRONAUT'S PIVOT AXIS
- STABILIZER GRIP ENVELOPE
- MMS MODULE HANDLING TOOL
- PAYLOAD REMOVAL CLEARANCE
- OCP AND APPLICABLE SATELLITE STRUCTURE



ASTRONAUT REACH RELATIVE TO PIVOT AXIS

An arbitrary "Reach Area Design Goal" established in the forward, lower quadrant of the available two-hand work area (defined per JSC-10615, "Shuttle EVA Description and Design Criteria", May 1976) was used for initial design guidance for accommodation of the full range of male/female percentiles.

The reach envelope capabilities of the full range suited astronauts, plus their vision capabilities, are the key to design of the OCP Payload Handling Device. The following delineates PHD design requirements:

Eye Location for Erect Standing Suited Astronaut

- Eye Height is 70.4 inches for a 95th percentile male and 56.4 inches for a 5th percentile female.
- Eye location forward of the astronaut pivot is 6 inches for the male and 4.5 inches for the female.

Maximum Reach Envelope for Suited Astronaut

Maximum reach is: 90° for hip and waist flexion/extension; 150° for shoulder rotation and 40° for ankle extension/flexion. These three parameters govern erect body tilt to a maximum of 40° forward, a maximum waist bend of 90° , and an upper arm rotation from straight down to 150° up.

Hand reach is 21.3 inches for a 95th percentile male and 17 inches for a 5th percentile female measured from the shoulder pivot.

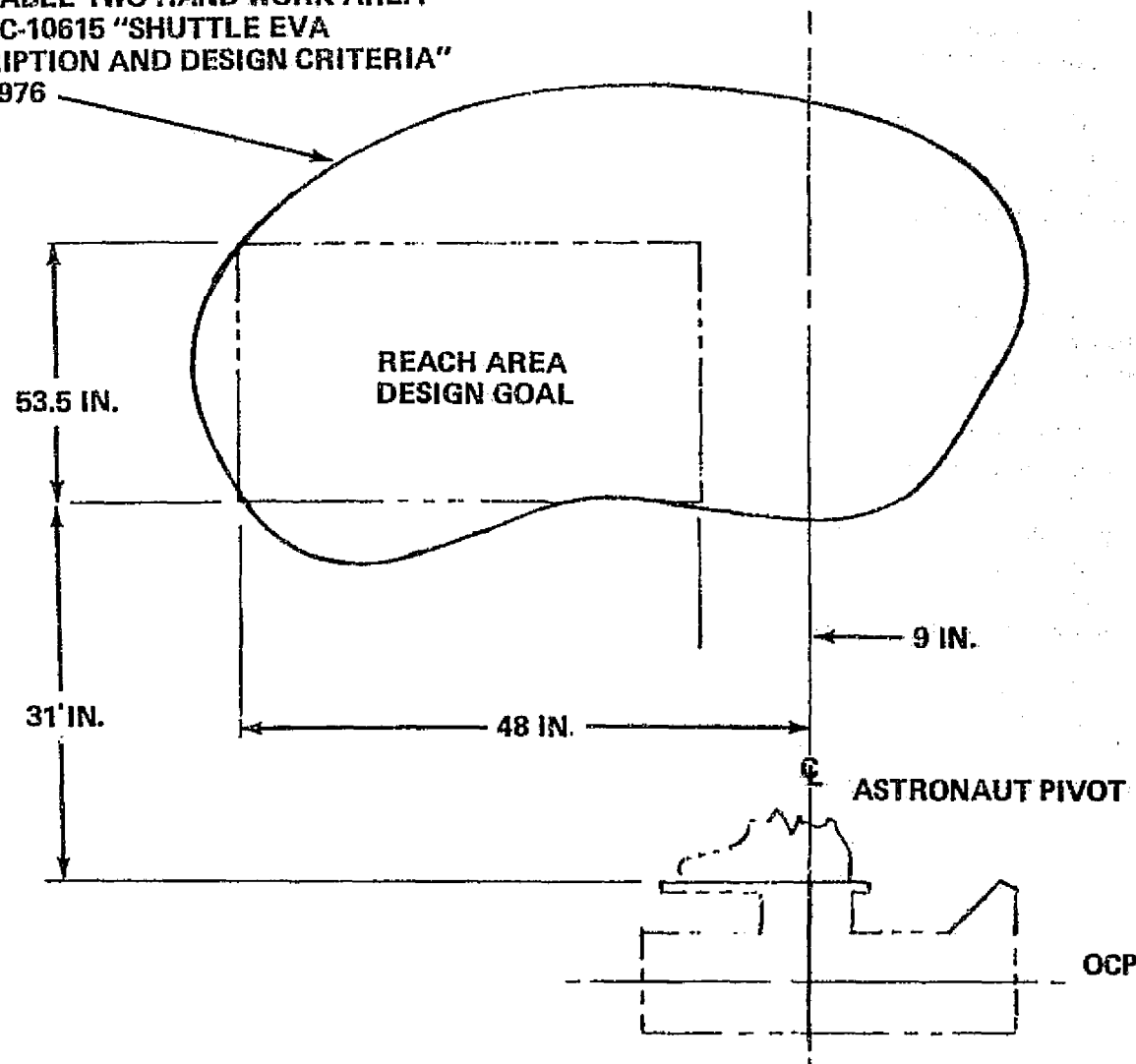
Shoulder pivot location is 61 inches for the 95th percentile male above and 50 inches above the standing platform for the 5th-percentile female.

Ankle pivot location is 4 inches above the platform for the 95th percentile male and 3 inches for the 5th-percentile female.

Using the data derived above, with the ankle as a datum pivot, it is possible to construct a hand reach envelope which is broader than that shown on JSC-10615 and which covers the percentile population.

ASTRONAUT REACH RELATIVE TO PIVOT AXIS

AVAILABLE TWO HAND WORK AREA
PER JSC-10615 "SHUTTLE EVA
DESCRIPTION AND DESIGN CRITERIA"
MAY 1976



GRUMMAN

STABILIZER REACH RELATIVE TO PIVOT AXIS

Two basic reach capability configurations of a Datum PAR 3000 type stabilizer system are depicted on the facing page.

One configuration depicts the hand as always parallel to the OCP longitudinal centerline. This provides information for available grapple area for a straight-on approach. The other configuration depicts maximum reach capability of the stabilizer and determines the maximum distance of a grapple point from the OCP to a shuttle cargo bay satellite berthing device.

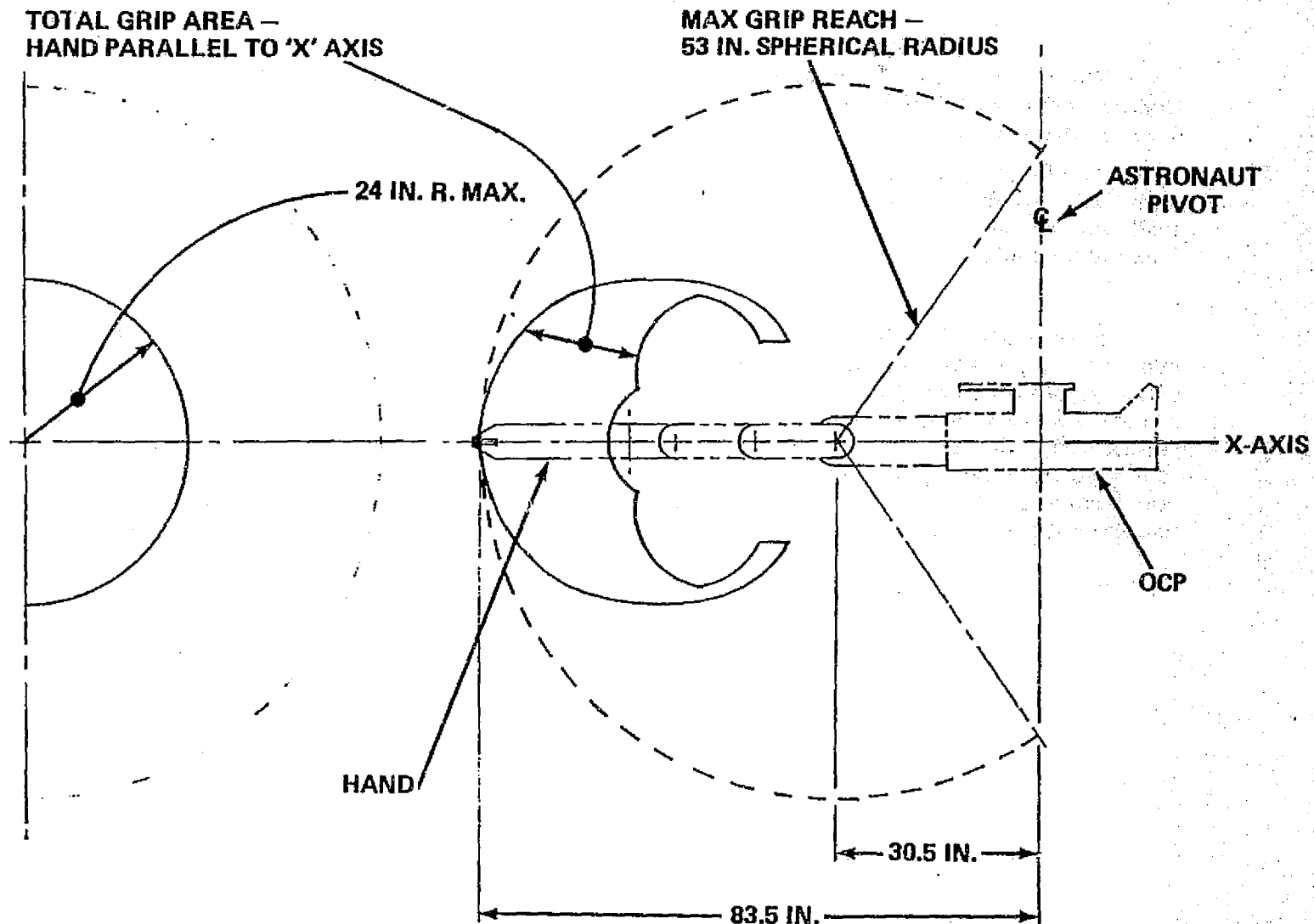
The addition of shoulder yaw increases available parallel hand grapple area. This is a desirable feature, but need not be incorporated at this time due to the lack of specific payload configuration data.

The stabilizer configuration at this time must be capable of grappling an unknown point at an unknown approach angle. Presently, it is assumed that the astronaut will have visibility to see the grapple point. If it is determined during DTA testing that remote grappling is required, a major impact to the OCP system will occur. A CCTV system will be required which will enlarge the C&D console, increase power requirements, weight, cost, and lighting. There is a good chance that a force sensing device will be required at the stabilizer jaw to provide force cues to the astronaut to prevent damage to the grapple point.

It is recommended that a common interface device be considered for all satellite berthing devices. This approach will permit a re-evaluation of the stabilizer concept which could result in a simple device which increases productivity. The design of the interface should consider its application to the closed cherry picker free flyer.

The reach envelopes shown provide an assessment of the distance between the astronaut, the berthing device, and the payload.

STABILIZER REACH RELATIVE TO PIVOT AXIS



GRUMMAN

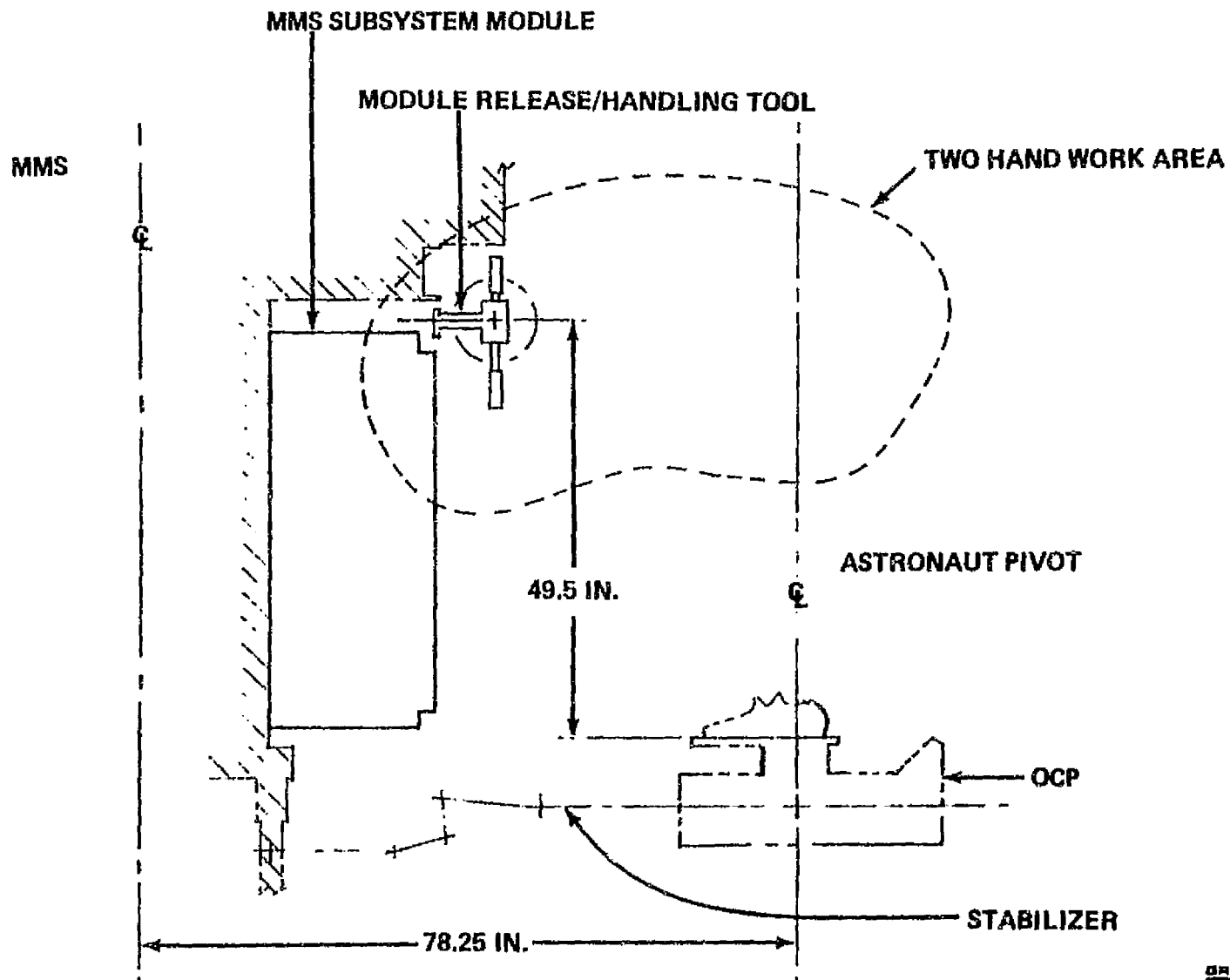
RELATIONSHIP — OCP/MMS WORK AREA

The Multimission Modular Spacecraft (MMS) described in the Goddard Space Flight Center Document "S-700-13", Revision A dated May 1977, was used as the initial candidate for the PHD design since the most detailed payload information exists.

The facing page shows the relationship of the astronaut's pivot on the OCP to the MMS, stabilizer attachment to the MMS berthing device, MMS structure which surrounds the payload, one of the three subsystem module payloads to be replaced, the NASA tool used to release and handle the payload, and the two-hand work area defined by JSC-10615.

Note that each of the three payloads are attached to the MMS structure at two points, one on the top centerline where the release tool is shown, and one on the bottom centerline which must be released by the same tool. Due to the spacing of these two pickup points, it is not possible to position the OCP at one location where the astronaut can reach both pickup points. This deteriorates productivity and therefore raises the question as to the advisability of developing single point release and handling of all payloads. This effort should attempt to standardize the interface tool, payload interface, and PHD interface, which in the end result in increased productivity.

RELATIONSHIP — OCP/MMS/WORK AREA



CLEARANCE CONSIDERATIONS

A list of major clearance considerations are shown on the facing page using the MMS as a sample configuration.

- Astronaut's EVA backpack clearance - The present OCP configuration assumes an astronaut stands in a near vertical position. A 24 inch radius from the platform pivot will provide sufficient clearance for the full range of suited astronauts.
- Console - Clearance must be provided between the payload, located at the stowed position, and the console, with its associated controls, at the off-line 135° rotated position. A total C&D panel growth to 29 inches shall be accommodated.
- MMS Payload Envelope - The payload, once it has been berthed to the PHD, must track clearly to its stowed position.
- MMS Structure - Particular attention must be given to insure clearance to the structural arrangement that supports the payloads.
- MMS Signal Conditioning and Control Unit - This unit protrudes on one side of the payload removal path.
- MMS Module Handling Tool - Clearance must be provided, not only for use of this tool, but for the tools translation during PHD motion and at the payload stowed position.
- Stabilizer - All motions required of the stabilizer from its stowed position to the grapple point are to be considered.
- OCP Structure - The OCP structure is the focal point for attachment of all the subsystems and must be considered in design of clearances.
- OCP Lights/Tool Box - These items, being of a stowable nature alongside the OCP, generate a stowage trajectory and space occupation which must be cleared by the PHD in the stowed configuration.

CLEARANCE CONSIDERATIONS (MMS PRESENTED AS WORST CONFIGURATION)

- **ASTRONAUT'S EVA BACKPACK CLEARANCE:**
 - 24 IN. RADIUS FROM FOOT RESTRAINT PIVOT
- **CONSOLE: POSITIONED OFF-LINE AT 135° ROTATION, PROVIDE WIDTH GROWTH TO 29 IN.**
- **MMS PAYLOAD ENVELOPE**
- **MMS STRUCTURE**
- **MMS SIGNAL CONDITIONING & CONTROL UNIT**
- **MMS MODULE HANDLING TOOL**
- **STABILIZER**
- **OCP STRUCTURE**
- **OCP LIGHTS/TOOL BOX**
- **SHUTTLE RMS**



CLEARANCE CONFIGURATION

A datum clearance configuration is depicted to show the overall relationship of the MMS to the astronaut's task of removing, stowing, and replacing an MMS subsystem module in accordance with the clearance considerations listed on the previous chart.

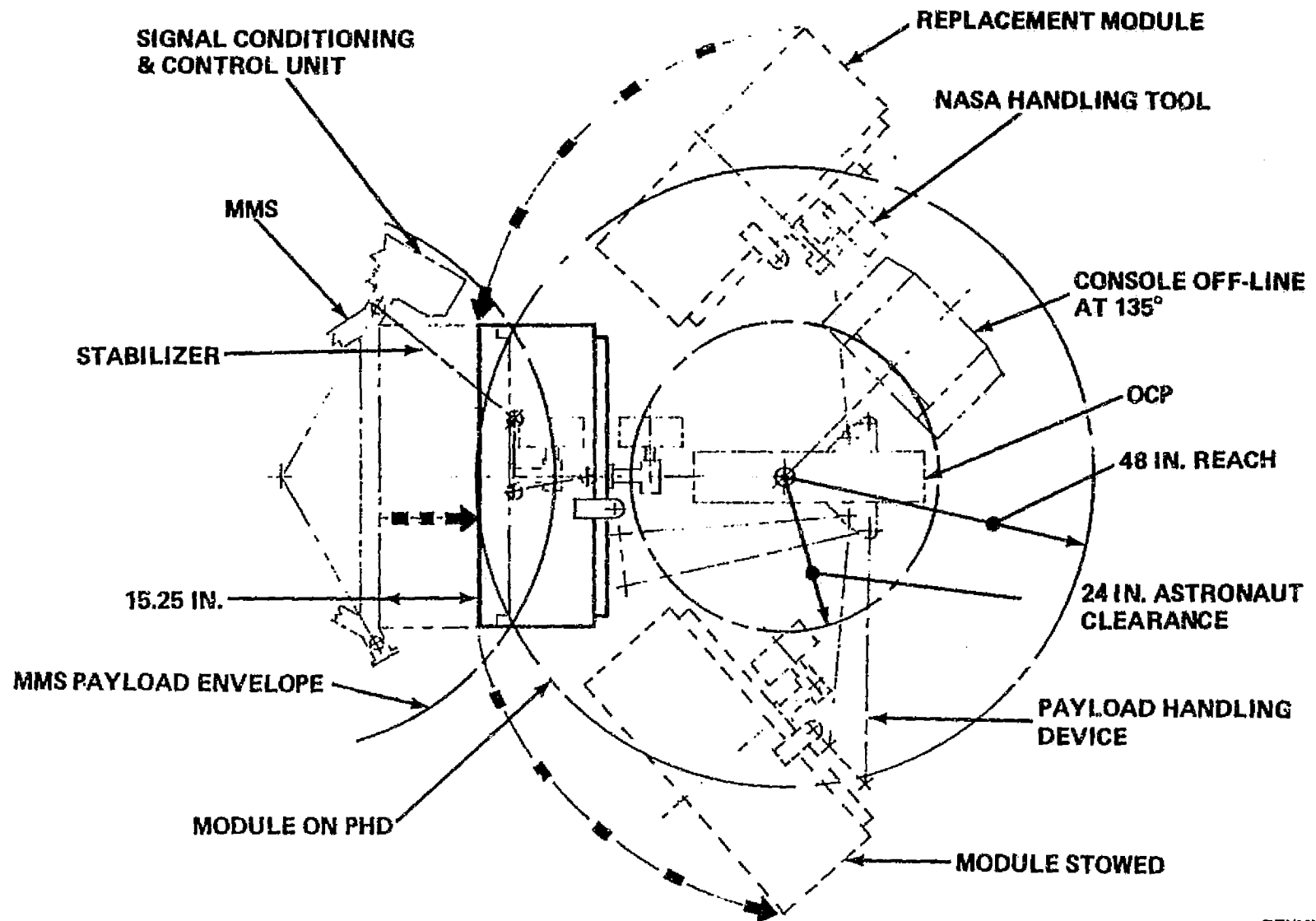
The PAR 3000 type stabilizer, with wrist yaw capabilities, is shown grappled to the shuttle cargo bay MMS berthing device structure. This sets up the relationship of the OCP to the payload. The MMS payload is shown attached to the MMS structure with the NASA handling tool attached. A 48 inch reach and a 24 inch clearance is circumscribed about the astronaut's pivot. The console is shown at the 135° rotation, off-line position. These conditions set the stage for MMS payload removal and stowage. The astronaut inserts the removal tool to the position shown, (assume lower connection previously released) breaks the bolt torque and winds out the lock bolt to free the payload. Using the tool as a handle, the astronaut pulls and guides the payload 15.25 inches away from the MMS structure being careful not to contact the signal conditioning and control unit. With the payload displaced to this position, a PHD supports the payload and then, by astronaut power, swings the MMS to a stowed position, which will not encroach on the astronaut clearance radius or any OCP subsystem. A pure radial swing will not clear; therefore, a four-bar linkage arrangement as shown is used to control the swing trajectory clearance.

This configuration imposes the requirement that the PHD and the payload are never within the 24 inch astronaut clearance. This permits the astronaut the option of translating the OCP to station with the unloaded payload in front, for aided alignment.

A left and right PHD is shown. The left hand PHD accepts the payload from the MMS while the right hand PHD carries the replacement module. Dotted trajectories are shown for clarity.

A further point that has been considered is that a common pickup location on a removed or to be replaced payload has been selected. This requires the left and right interfaces to meet at the same location forward of the astronaut.

CLEARANCE CONFIGURATION



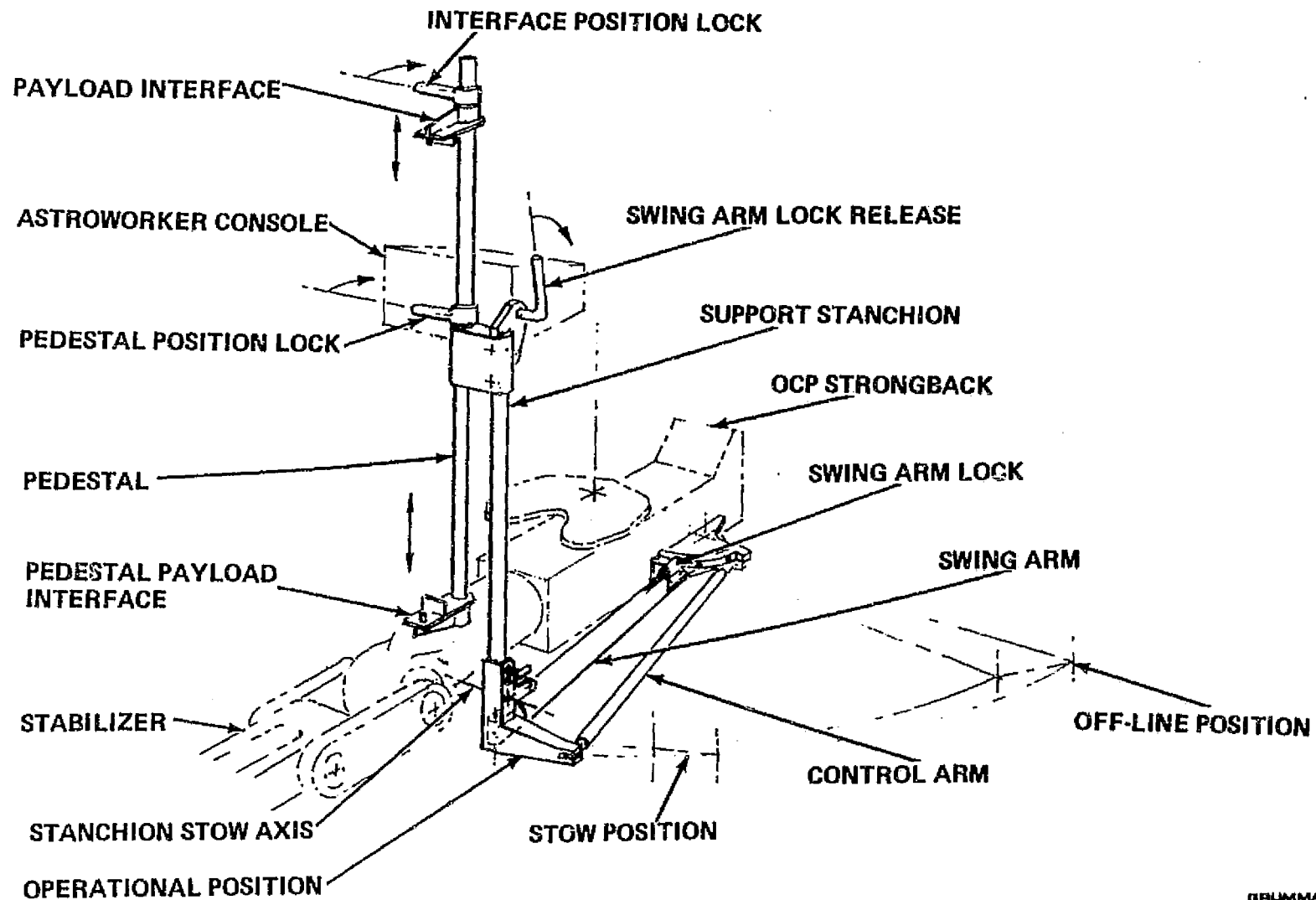
PAYLOAD HANDLING DEVICE (LEFT HAND SHOWN)

A perspective of the left hand installation of the datum PHD system is depicted with appropriate identification of the major components discussed below.

- Payload Interfaces - Two payload interfaces are shown to accommodate rectangular shapes such as the MMS subsystem module. The lower interface is fixed to a pedestal; the upper interface is vertically adjustable and lockable on the pedestal by the astronaut. This permits the attachment of various height payloads discussed previously.
- Pedestal - A pedestal is provided to support the payload interfaces. The pedestal can be vertically adjusted and locked to the support stanchion by the astronaut. This allows the astronaut to adjust the vertical position of the interfaces for optimum alignment and translational clearances for the payload.
- Support Stanchion - A support stanchion is provided to support the pedestal, interface with the swing arm, and provide for the optimum location of a swing arm release.
- Swing Arm/Control Arm - A swing arm is provided to support the payload and swing it to the off-line position (payload stow position). The control arm makes up the four-bar linkage arrangement to provide the required payload swing clearances.
- Swing Arm Lock - A swing arm lock system is provided to lock the swing arm at three specific positions; operational for payload pickup, stow for PHD stowage, and off-line for payload stowage or payload replacement unit. Any number of intermediate positions may be obtained, as determined by the DTA or as required by additional requirements.

Many degrees of flexibility have been incorporated into the design concept to permit a complete evaluation of all aspects in the usage of the PHD and compatibility to undefined payloads.

PAYLOAD HANDLING DEVICE (L.H. SIDE SHOWN)

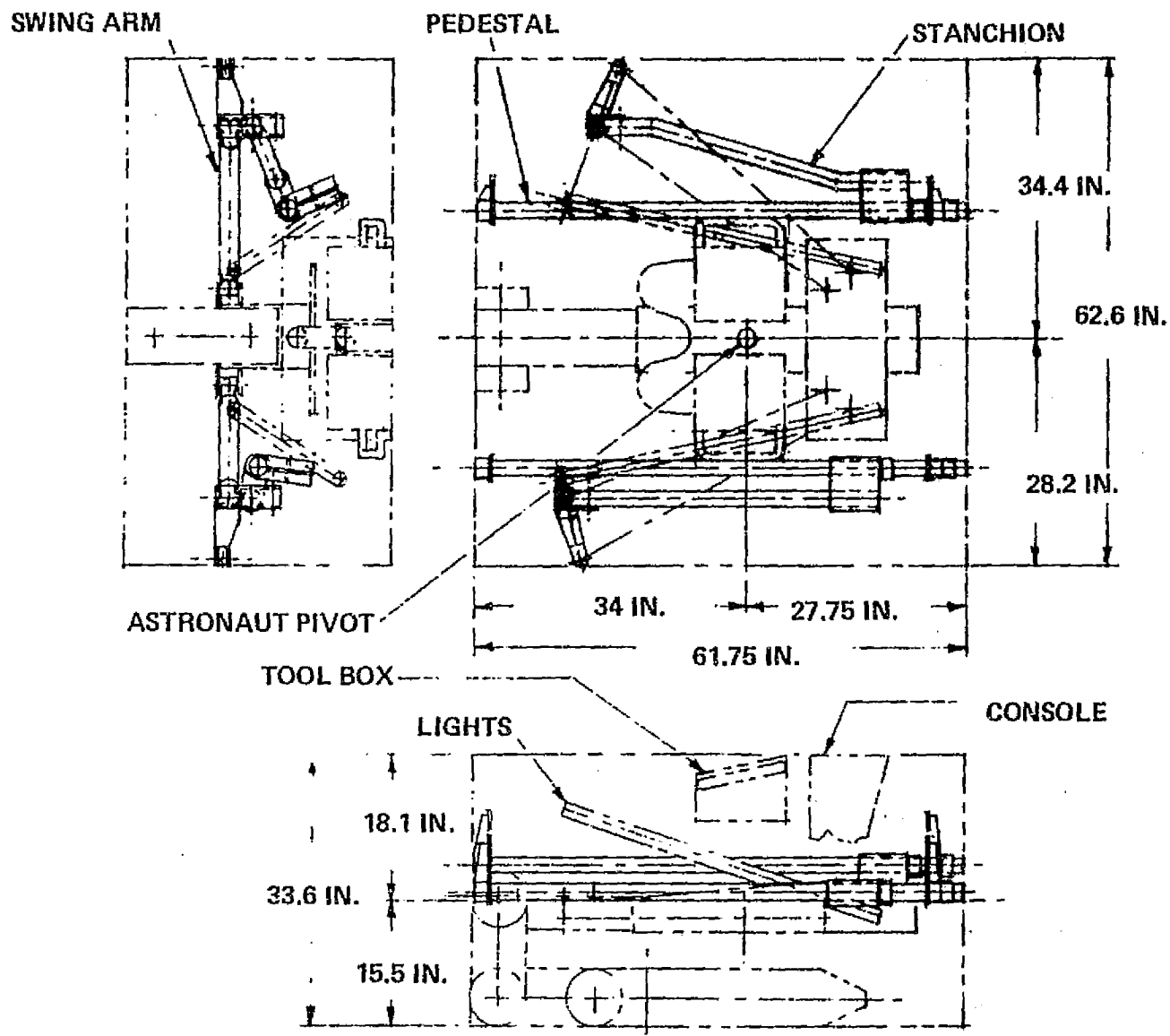


PHD STOWED CONFIGURATION NO. 1.

This configuration is considered to be the datum design. It requires 6 operations to deploy and 9 operations to stow. It is the widest of the three configurations being presented.

The PHD, after the stabilizer, is the first of the OCP subsystems to be stowed. It must stow under all the subsystems and/or outboard of them. The pacing clearance is between the folding PHD pedestal and the light stanchions. This basically requires the pedestal centerline to be folded at a distance no less than 16 inches from the centerline of the OCP. With the geometry shown, this places the stanchion fold fitting, that attaches to the swing arm, at an outboard position that controls the maximum width of the stowed configuration.

P.H.D. STOWED CONFIGURATION NO. 1



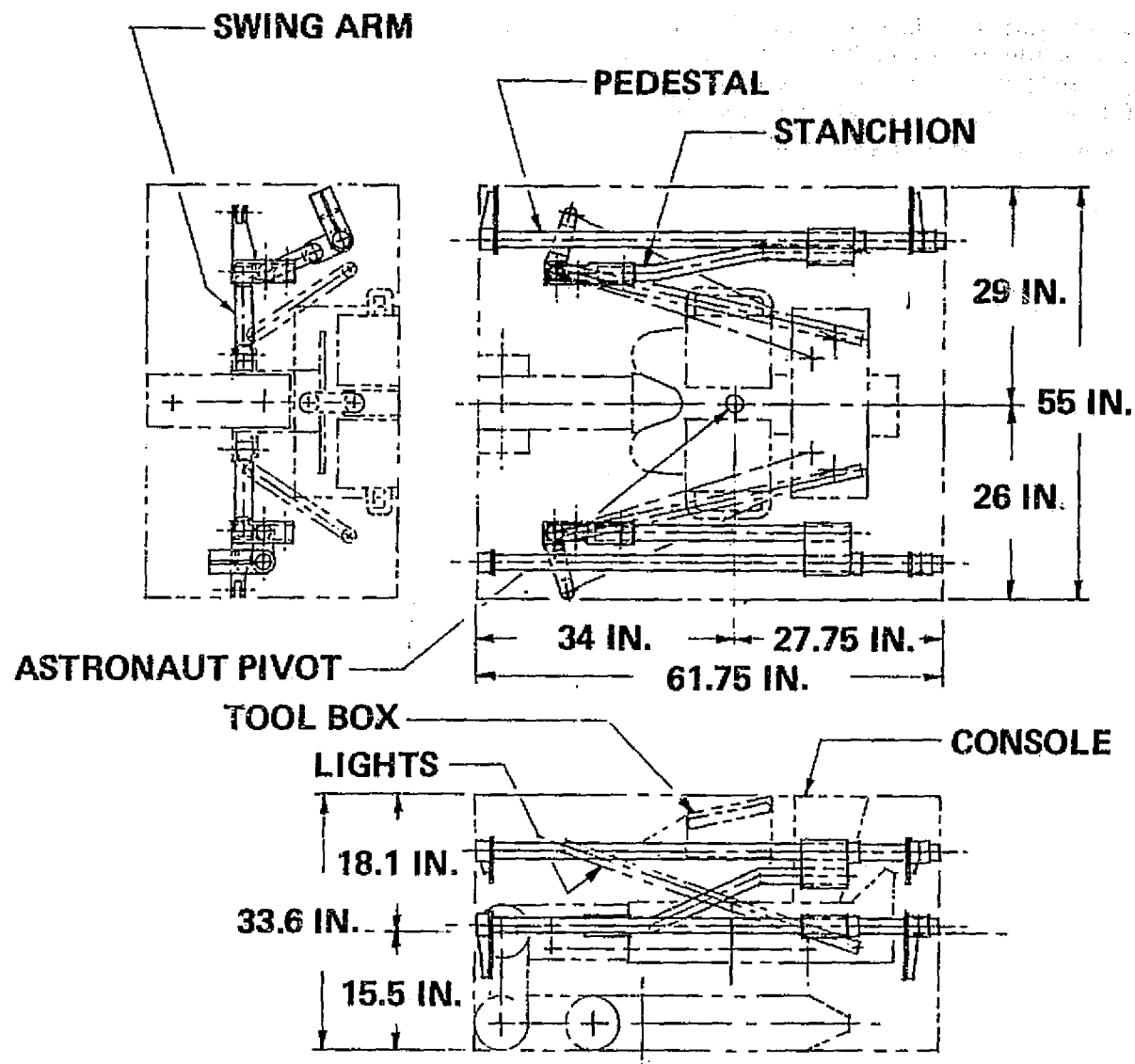
ORIGINAL PAGE IS
UNCLASSIFIED

BRUMMAN

PHD STOWED CONFIGURATION NO. 2

This configuration is identical to the datum configuration except that the stanchions are rotatable to allow the swing arm to be indexed further inboard toward the center of the OCP resulting in a 7.6 inch reduction of overall width. This configuration will require a greater number of operations, i. e., 8 to deploy and 11 to stow.

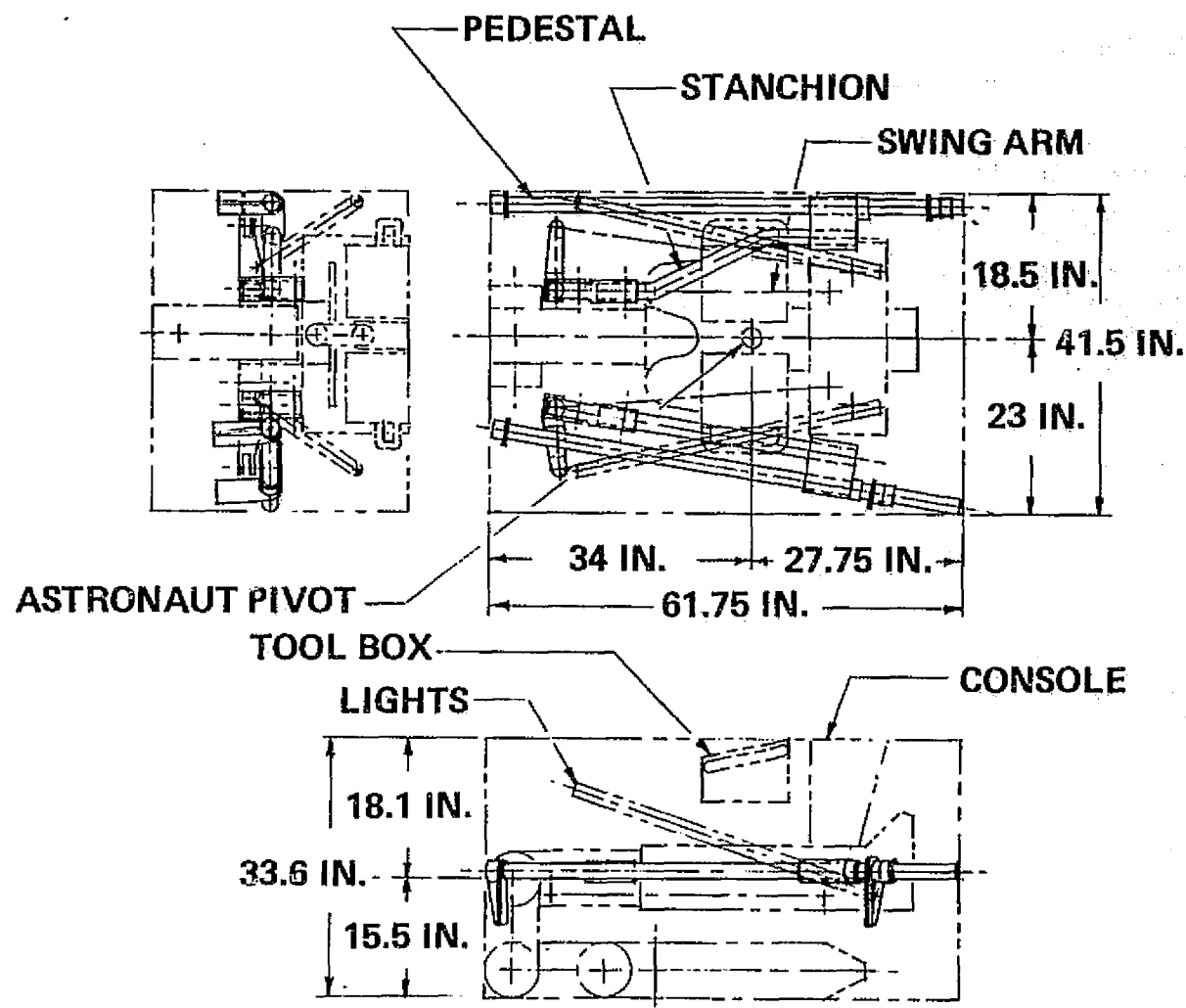
PHD STOWED CONFIGURATION NO. 2



PHD STOWED CONFIGURATION NO. 3

This configuration is identical to configuration No. 2 except that the swing arm is indexed closer to the center of the OCP. This places the stanchions in a position where, when they are erected, they will collide with the console unless the console is positioned at the 180° position (full aft). The total width is reduced by 21.1 inches, however, the number of operations increase; i. e., 9 to deploy and 12 to stow.

PHD STOWED CONFIGURATION NO. 3



ORIGINAL PAGE IS
OF POOR QUALITY



COMPARISON OF THE NUMBER OF OPERATIONS FOR DEPLOYMENT/STOWAGE OF PHD CONFIGURATIONS 1, 2, AND 3

The facing page tabulates the specific operations and the number of operations required to deploy and stow configurations 1, 2, and 3.

The left hand column lists the operations required to deploy each of the candidate configurations and then lists all the operations required to stow the configurations.

To the right are two sections denoting "DEPLOY" and "STOW" with each of the three configurations listed underneath. The numbers under the specific configuration; i.e., 1, 2, etc., denote the operation sequentially. As an example, when swinging the left hand stanchion up during deployment, it is the 3rd operation required for Configurations 1 and 2, and the 4th operation required for Configuration 3. The 2nd operation for the latter is to position the console to 180° aft. Stowing operations can be viewed the same way with a quick reference available where they deviate.

COMPARISON OF THE NUMBER OF OPERATIONS FOR DEPLOYMENT/STOWAGE OF PHD CONFIGURATIONS 1, 2 AND 3

| | CONFIGURATIONS | | | | | |
|------------------------------------|----------------|---|---|------|----|----|
| | DEPLOY | | | STOW | | |
| | 1 | 2 | 3 | 1 | 2 | 3 |
| • UNFOLD CONSOLE | 1 | 1 | 1 | | | |
| • UNFOLD LIGHTS/TOOL BOX | 2 | 2 | 2 | | | |
| • POSITION CONSOLE TO 180° AFT | | | 3 | | | |
| • UNFOLD LH PHD | | | | | | |
| — SWING STANCHION UP | 3 | 3 | 4 | | | |
| — ROTATE STANCHION | | 4 | 5 | | | |
| — POSITION SWING ARM | 4 | 5 | 6 | | | |
| • UNFOLD RH PHD | | | | | | |
| — SWING STANCHION UP | 5 | 6 | 7 | | | |
| — ROTATE STANCHION | | 7 | 8 | | | |
| — POSITION SWING ARM | 6 | 8 | | | | |
| • POSITION CONSOLE TO FWD POSITION | | | 9 | 1 | 1 | |
| • POSITION CONSOLE TO 180° AFT | | | | | | 1 |
| • POSITION RH SWING ARM | | | | 2 | 2 | 2 |
| • POSITION RH PEDESTAL AND CLAMP | | | | 3 | 3 | 3 |
| • STOW RH PHD | | | | | | |
| — ROTATE STANCHION | | | | | 4 | 4 |
| — SWING STANCHION DOWN | | | | 4 | 5 | 5 |
| • POSITION LH SWING ARM | | | | 5 | 6 | 6 |
| • POSITION LH PEDESTAL AND CLAMP | | | | 6 | 7 | 7 |
| • STOW LH PHD | | | | | | |
| — ROTATE STANCHION | | | | | 8 | 8 |
| — SWING STANCHION DOWN | | | | 7 | 9 | 9 |
| • POSITION CONSOLE FWD | | | | | | 10 |
| • FOLD LIGHTS/TOOL BOX | | | | 8 | 10 | 11 |
| • FOLD CONSOLE | | | | 9 | 11 | 12 |



SUMMARY OF STOWAGE CONFIGURATION DATA

A summary of the stowage configuration data is presented.

The summary points out the following:

- Height and length of the stowed configurations are unaffected and therefore remain the same for all three options.
- The number of operations required "to deploy" or "to stow" increase as the stowed width decreases.

Reduced width in Configurations 2 and 3 is accomplished by adding a stanchion rotation.

Configuration 3 also requires that the C&D console be at the 180° position prior to PHD folding.

The following issues require more investigation:

- Do a few additional operations significantly reduce time on station?
- Is the additional complexity and/or delta time on station justified by the need for the additional cargo bay stowage volume?

In addition, it has been shown that large tools like the Skylab sheet metal cutters can be stowed on the pedestal. Further analysis is required to determine if other large tools or objects could benefit from stowage on the PHD pedestal.

SUMMARY OF STOWAGE CONFIGURATION DATA

| CONFIGURATION | NO. OF OPERATIONS | | VOLUME | | |
|---------------|-------------------|---------|--------|--------|-------|
| | TO DEPLOY | TO STOW | HEIGHT | LENGTH | WIDTH |
| 1 | 6 | 9 | 33.6 | 61.75 | 62.6 |
| 2 | 8 | 11 | 33.6 | 61.75 | 55.0 |
| 3 | 9 | 12 | 33.6 | 61.75 | 41.5 |

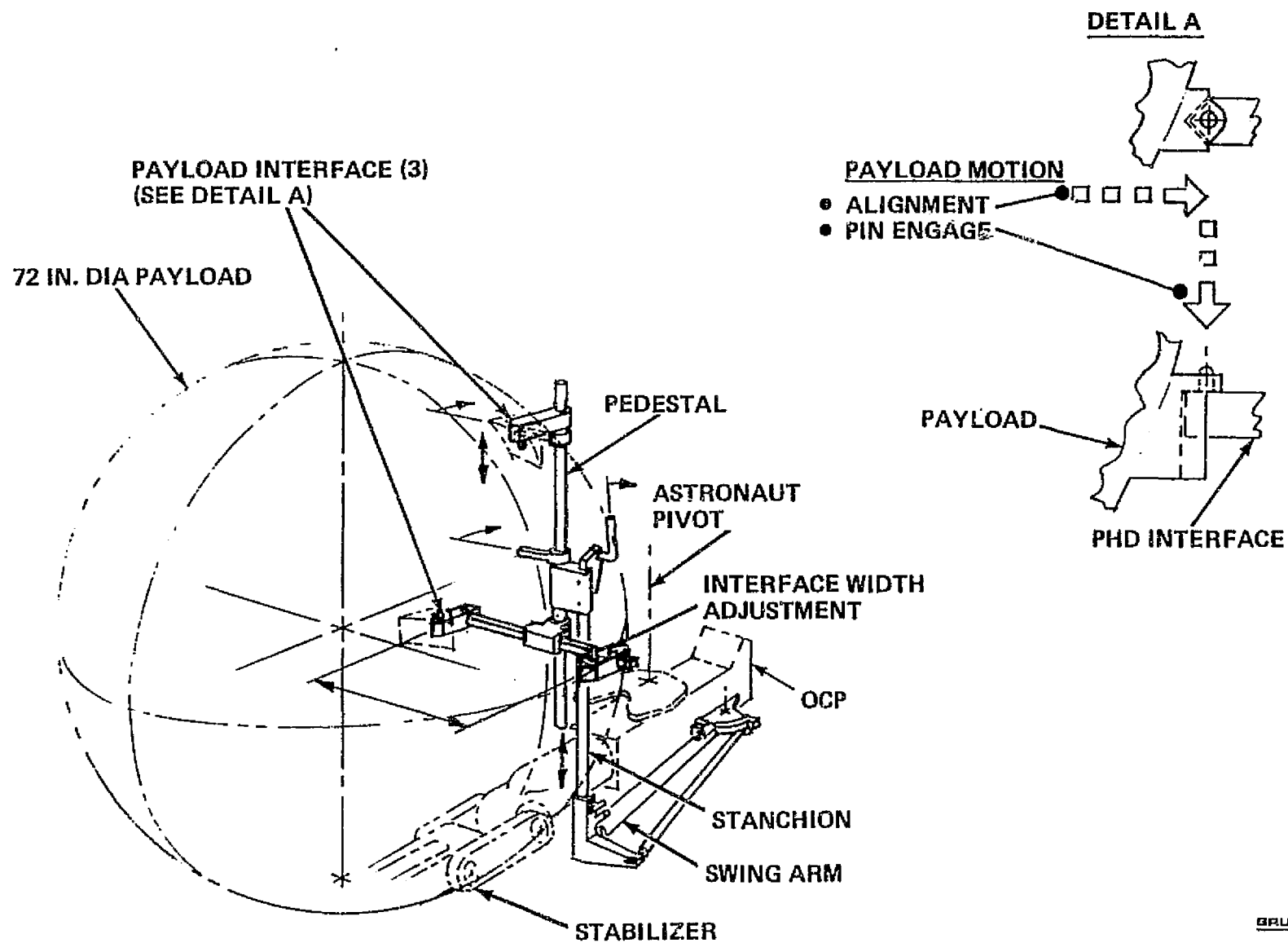


PHD INTERFACE CONCEPT FOR SPHERES

Under the requirements for a PHD it was determined that three generic shapes would be handled. The rectangular shape is covered in the discussions of the MMS payload. The perspective on the facing page depicts a concept for handling spherical objects up to 72 inches in diameter.

Conceptually, after the sphere has been disconnected, the astronaut pulls the sphere to engage its vee-notch and flange to align with the PHD wedges, then pushes the sphere down to engage the flange hole with the PHD interface pin (see detail "A"). Once the sphere is engaged, the upper single interface is pushed down to engage and lock. Procedures are now similar to the MMS module payload discussed previously.

PHD INTERFACE CONCEPT FOR SPHERES



PHD PAD-TYPE INTERFACE CONCEPT FOR SPHERES

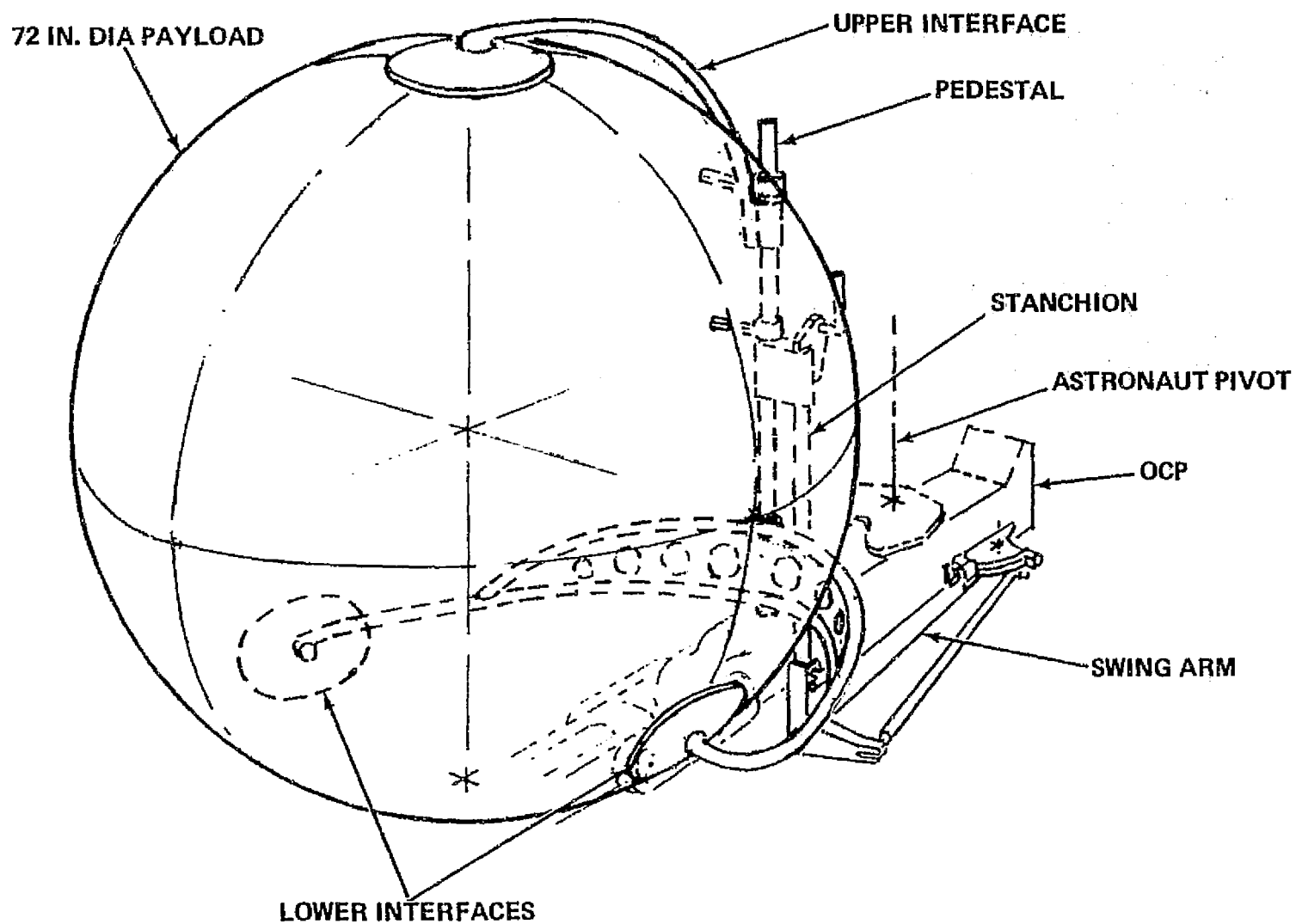
Continuing with the requirement for the PHD to handle spheres, the perspective on the facing page depicts a concept for supporting spheres by three large concave pads.

The pad approach reflects a concept which does not require any specific interface to be provided on the sphere. If all spherical objects have a smooth area to match the pad supporting geometry, the concept is viable; however, if you consider a range of small-to-large spheres it appears that you will also need a family of pad designs to accommodate them. In addition, these pads will not remain visible to the astronaut during payload berthing and could cause significant productivity loss.

A tradeoff is required with the non-pad interface previously presented. Issues to be addressed are: specific or anticipated sphere sizes; surface characteristics and number of different interfaces required; impact of an interface device on the sphere; method of disconnecting sphere from the payload; types of handling tools required; service disconnect requirements.

ORIGINAL PAGE IS
OF POSITIVE QUALITY

PHD PAD TYPE INTERFACE CONCEPT FOR SPHERES



ORIGINAL PAGE IS
OF POOR QUALITY

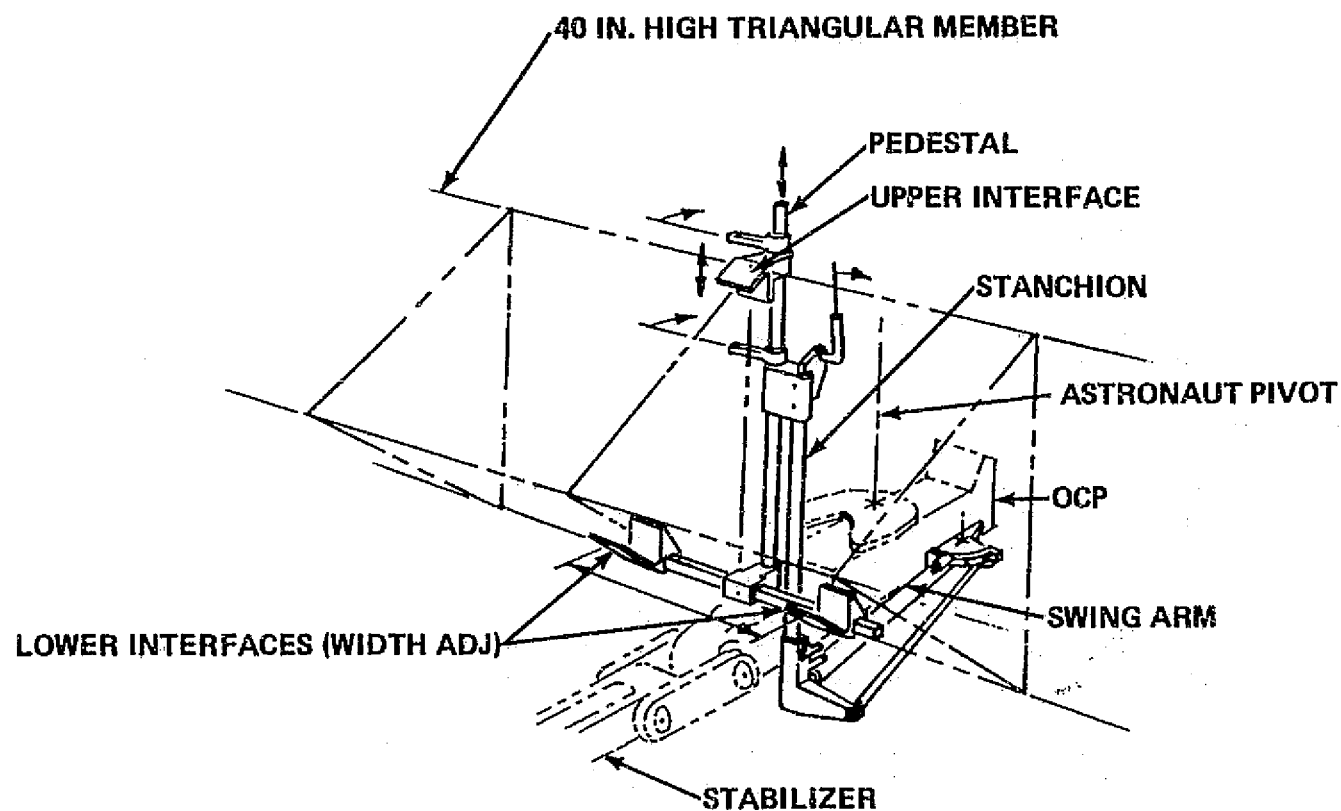
PHD INTERFACE CONCEPT FOR TRIANGLES

The third generic shape that the PHD is required to handle is the triangle. The perspective on the facing page depicts a concept for handling this shape, which in this case represents a one-meter beam structure of considerable length. Shorter objects, representing payloads, would be carried as replacements similar to the MMS modules.

The three payload interfaces shown have replaced the two rectangular payload interfaces on the common pedestal. The two lower interfaces slide and lock to a horizontal bar to provide a width adjustment capability.

Conceptually, after the triangular payload has been disconnected from its satellite, the astronaut first pulls the payload to engage the lower set of interfaces on the PHD, and then lowers the upper interface to lock the payload in position. Procedures are now similar to the MMS module payload.

PHD INTERFACE CONCEPT FOR TRIANGLES



ORIGINAL PAGE IS
OF POOR QUALITY



SUMMARY

Design

- The requirements have been met to permit the range of 5th percentile female through 95th percentile male EVA astronaut to remove and replace rectangular, spherical, and triangular payloads.
- The design constraints have been met for the astronaut's reach capability from the OCP astronaut's pivot axis, with handling tools, the PHD, and the OCP subsystems.
- Clearances have been accomplished as demonstrated by the datum design configuration.
- The datum design has resulted in a flexible configuration that provides for a family of interface devices that will accommodate the three generic payloads.

Areas for Investigation

- A list of payload candidates is required for an evaluation of the capabilities of the PHD and to bring to light any potential problem areas involving access, vision, grappling, and handling of the payload.
- "Astronaut/Payload Handling Tool" commonality designs that will reduce the number of tools required, potentially establish a one point release, reduce cost, and certainly improve productivity, should be investigated.
- "Payload/PHD Interface" commonality that reduces the number of interface requirements, and improves productivity, should be studied.
- The need for captive-guided removal of heavy, high inertia payloads must be evaluated in terms of available clearances, the distance the astronaut translates it to the PHD, and productivity level.
- The stabilizer grapple point should be studied by reviewing the applicable satellite berthing device and its relationship to the payload. Optimally, it would be desirable to have a standard grapple interface compatible to the payload location. This could result in a simplistic drogue engagement-type of device which would certainly improve productivity and reduce complexity.

SUMMARY

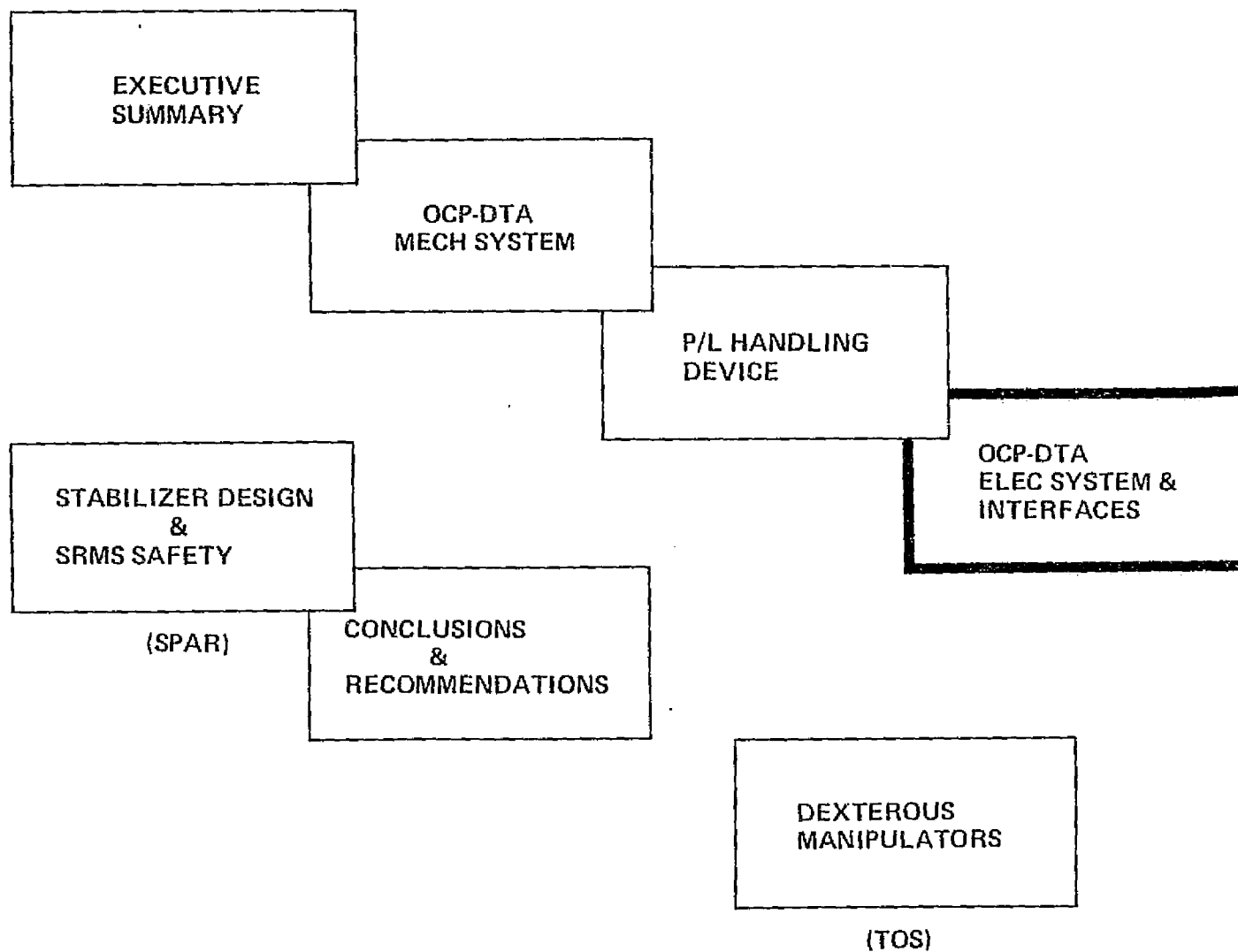
DESIGN

- **REQUIREMENTS HAVE BEEN MET**
- **CONSTRAINTS HAVE BEEN ADDRESSED**
- **CLEARANCES HAVE BEEN ACCOMPLISHED**
- **DATUM DESIGN PROVIDES FRAMEWORK FOR:**
 - **ATTACHMENT OF FAMILY OF PAYLOAD INTERFACE DEVICES**
 - **OPERATING, OFF-LINE AND STOWAGE PROVISIONS**

AREAS FOR INVESTIGATION

- **LIST OF PAYLOAD CANDIDATES**
- **"ASTRONAUT/PAYLOAD HANDLING TOOL" COMMONALITY**
- **"PAYLOAD/PHD INTERFACE" COMMONALITY**
- **NEED FOR CAPTIVE-GUIDED REMOVAL OF PAYLOADS EXCEEDING TBD WEIGHTS/INERTIAS**
- **STABILIZER GRAPPLE POINT**



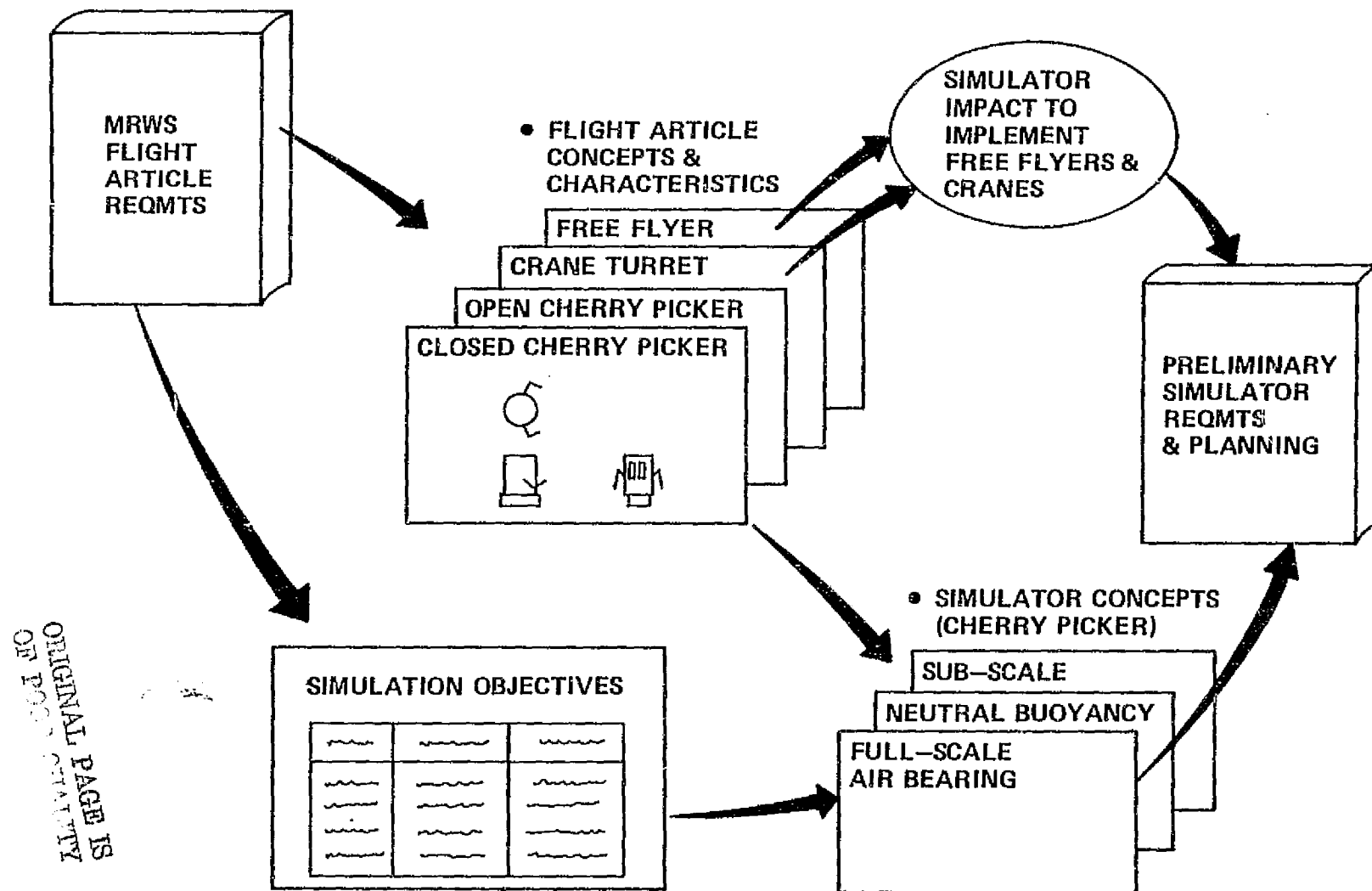


SIMULATOR REQUIREMENTS DEFINITION APPROACH

The results of design efforts and requirements analysis on the MRWS flight article are used to formulate simulator test objectives. This is then used as the basis for defining DTA and simulator system concepts.

The zero g simulator design concepts emphasize the utilization of a full-scale open cherry picker on the airbearing table. The present task activity involves developing real-time simulator requirements and planning for the MDF airbearing simulator and OCP DTA.

SIMULATOR REQUIREMENTS DEFINITION APPROACH



ORIGINAL PAGE IS
OF POC CREATIVITY

PRESENTATION AGENDA

The presentation agenda will be to discuss simulation priorities, electrical subsystem design issues, the PDR electrical design and finally, the approach to test plan development.

PRESENTATION AGENDA

- **SIMULATION PRIORITIES**
- **ELECTRICAL SUBSYSTEM DESIGN ISSUES**
- **PDR ELECTRICAL DESIGN**
- **TEST PLAN DEVELOPMENT**

PRIORITIZED SIMULATION OBJECTIVES IN MDF

The simulation objectives were prioritized for early definition of OCP subsystem design requirements. A series of real-time simulation developments tests involving a high fidelity mission environment, OCP/simulated SRMS, astronaut procedures and support equipment will be developed in the prioritized order. The emphasis will be to evaluate technical issues of the OCP design by testing. In addition, the simulator will be used to develop astronaut timelines, procedures, and validate MRWS candidate support equipment.

A key mission environment issue in developing the stabilizer design requirements is the dynamics of the SRMS when subjected to astronaut induced loads.

A key mission environment issue involving the development of Displays and Controls design requirements is the design implementation of control command and annunciation feedback in an environment of direct sun impingement on the D&C panel.

PRIORITIZED SIMULATION OBJECTIVES IN MDF

1. STABILIZER VS NON-STABILIZER

- TEST UNDER RELATIVE MOTION AT WORK STATION
- TEST UNDER INDUCED LOAD FEEDBACK TO RMS (BACK DRIVE)
- TEST TO SATELLITE SERVICING WORK FUNCTION REQUIREMENTS
 - EVA TOOLS
 - SPECIAL WORK ARTICLES (ARTICULATED)

2. D&C FUNCTION

- HAND CONTROLLERS
- SWITCH & ANNUNCIATION
- DISPLAYS
 - DIRECT SUN
 - PWR REQUIREMENTS

3. STS INTERFACES

- ELECTRICAL — DATA BUS, COMMO, INSTRUMENTATION, POWER, GPC
- MECHANICAL — FUNCTIONAL
- SOFTWARE — GPC

4. ASTRONAUT — PROCEDURES & TIMELINES

5. ASTRONAUT — SUPPORT EQUIPMENT

- TOOLS
- MONITOR & C/O INSTRUMENTATION
- PAYLOAD HANDLING DEVICE



STABILIZER DESIGN REQUIREMENTS

OCP simulation studies will be conducted to define the stabilizer design requirements, namely: degrees of freedom, control modes, end effectors, software and electromechanical interface to the SRMS and OCP systems.

STABILIZER DESIGN REQUIREMENTS

- NUMBER OF DEGREES OF FREEDOM
- END EFFECTORS
- CONTROL SYSTEM MODES OF OPERATION, i.e.
 - DIRECT SINGLE AXIS DRIVE
 - RESOLVED RATE DRIVE
- ELECTROMECHANICAL SUBSYSTEM I/F COMPATABILITY
- SOFTWARE



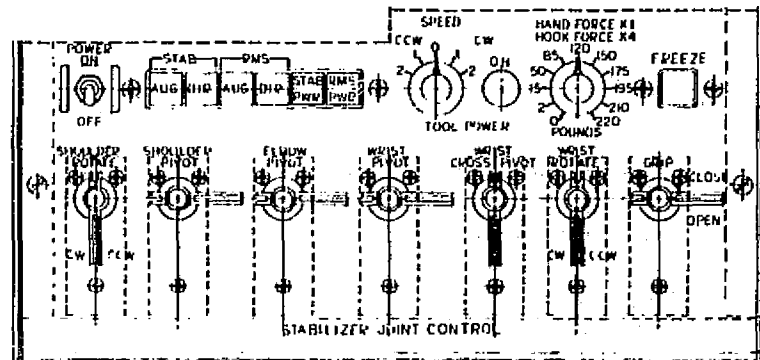
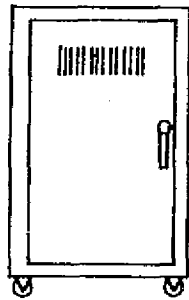
STABILIZER SYSTEM

The Stabilizer Systems consists of Control Panel, Power Control Center and Stabilizer Assembly. The Stabilizer Assembly has seven degrees-of-freedom and each joint in the direct drive mode is controlled by individual switches located on the Control Panel. These switches produce a continuously variable output in each direction from the center off position and are spring returned to center. The velocity of each joint is proportional to the displacement of the switch from the center position. The Control Panel also contains switches for control of power ON/OFF, tool power, and end effector force and mode selection.

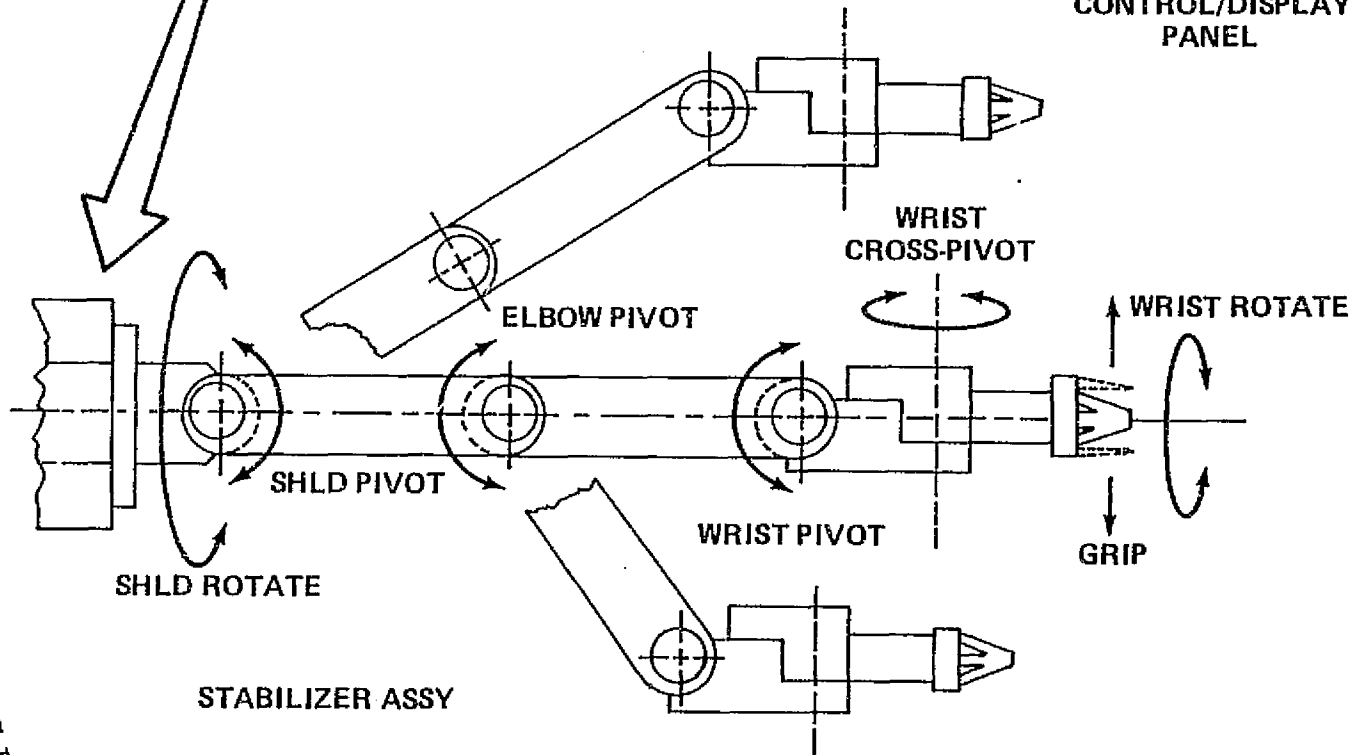
The Power Control Center contains the electronics for the power supply and joint motor drive controls. All control signals from the Control Panel are routed to the Power Control Center and then to the Stabilizer Assembly. The Stabilizer Assembly is designed so that the Wrist Assembly remains parallel to its initial orientation whenever the Shoulder Pivot or Elbow Pivot are rotated.

STABILIZER SYSTEM

POWER CONTROL CENTER



CONTROL/DISPLAY PANEL



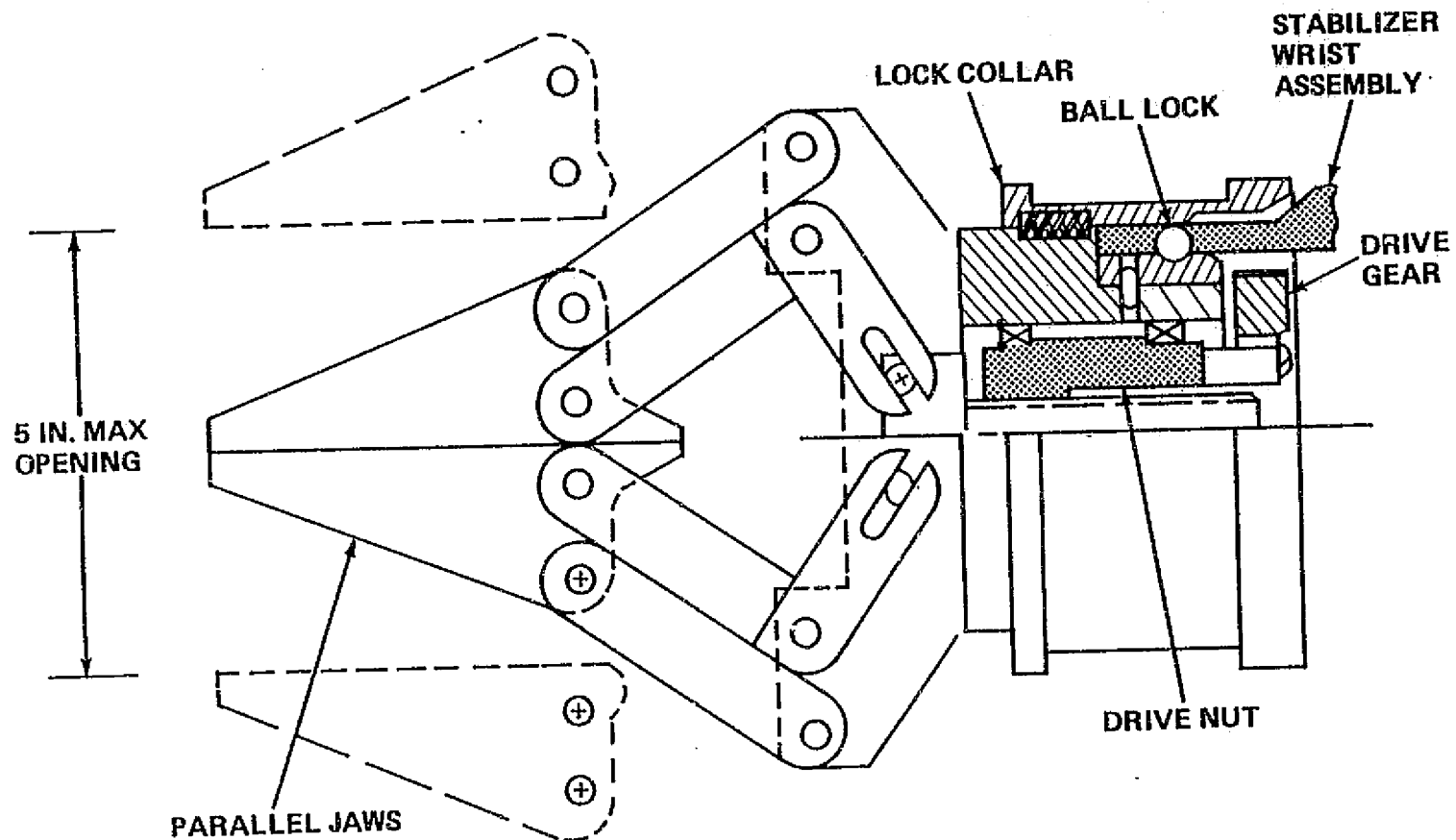
STABILIZER ASSY

ORIGINAL PAGE IS
OF POOR QUALITY

HAND END EFFECTOR PAR 3000 STABILIZER

One of the end effectors available for the stabilizer is a parallel jaw hand assembly as shown on the opposite page. The jaws can open to a maximum of 5 inches and can be driven at a maximum velocity of 18 inches per minute. The grip force can be varied from 0 to 200 pounds by means of a switch on the Control Panel. The hand end effector can be removed from the end of the Stabilizer Wrist Assembly by sliding the lock collar forward, which releases the ball lock, and pulling the hand assembly straight forward. If there is a failure in the Stabilizer Arm Assembly and the arm is grappled to a test article, the hand end effector can be removed as outlined above, and the jaws opened by turning the drive gear. Electrical driven tools such as drills or impact wrenches can be adapted so that they are held by the hand end effector. An electrical receptical is located on the Wrist Assembly for tool power and control switches on the Control Panel can vary the speed and rotational direction of the tools.

HAND END EFFECTOR – PAR 3000 STABILIZER



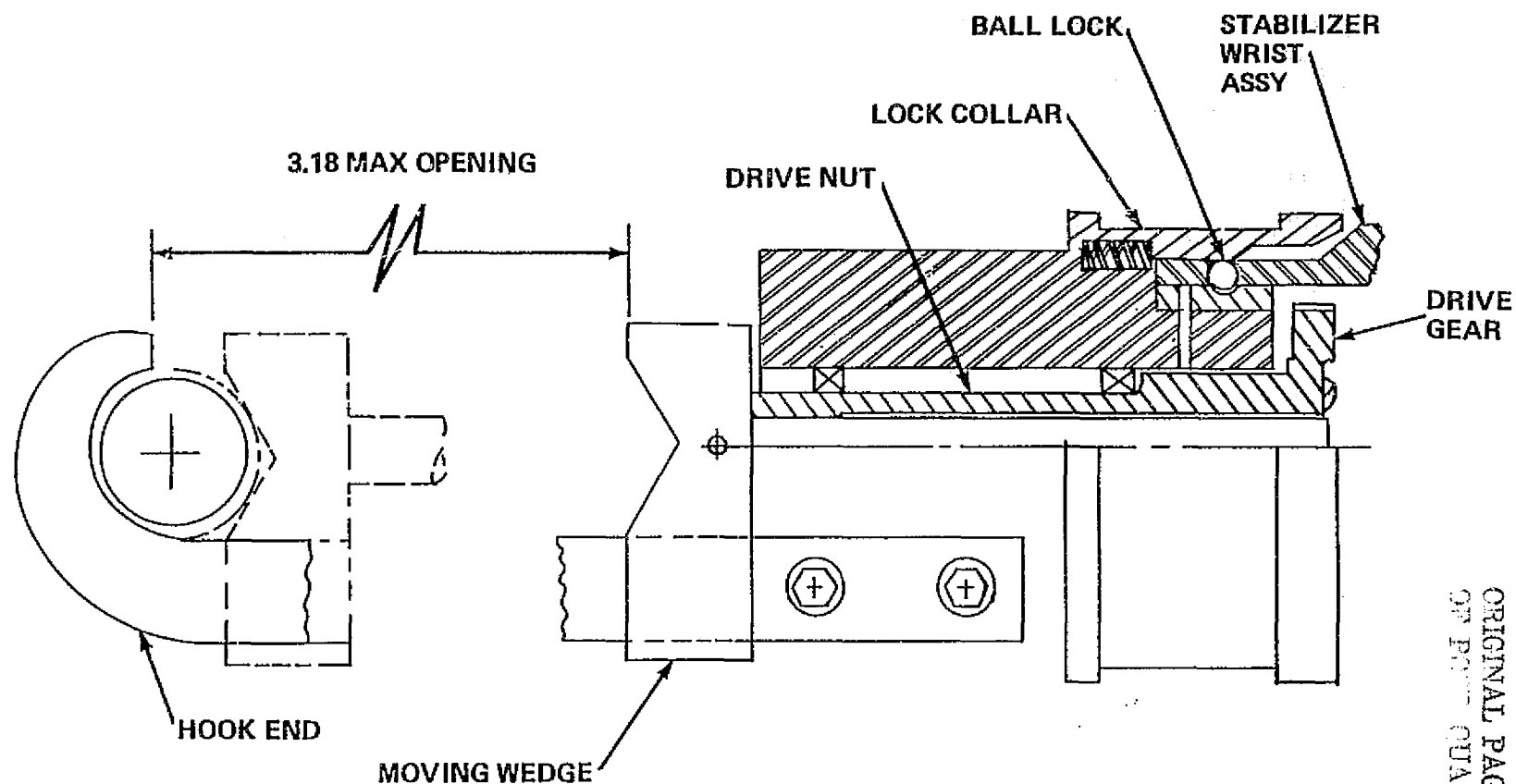
- FORCE VARIABLE 0 – 200 LB
- MAX OPEN-CLOSE VELOCITY 18 IN./MIN

ORIGINAL PAGE IS
OF POOR QUALITY

DOUBLE HOOK END EFFECTOR PAR 3000 STABILIZER

Another of the end effectors available for the PAR 3000 stabilizer is a double ended hook assembly. The hook opening can be varied to a maximum opening of 3.18 inches and driven at a maximum velocity of 5 inches per minute. The hook force can be varied from 0 to 800 pounds by means of a switch on the Control Panel. If there is a failure in the Stabilizer Arm Assembly, the hook can be removed from the Wrist Assembly in the identical manner described for the hand end effector. A single hook end effector is also available.

DOUBLE HOOK END EFFECTOR – PAR 3000 STABILIZER



ORIGINAL PAGE IS
OF POOR QUALITY

- SINGLE HOOK ALSO AVAILABLE
- FORCE VARIABLE: 0 – 800 LB
- MAX OPEN-CLOSE VELOCITY: 5 IN./MIN
- 5 IN. HOOK END SPACING

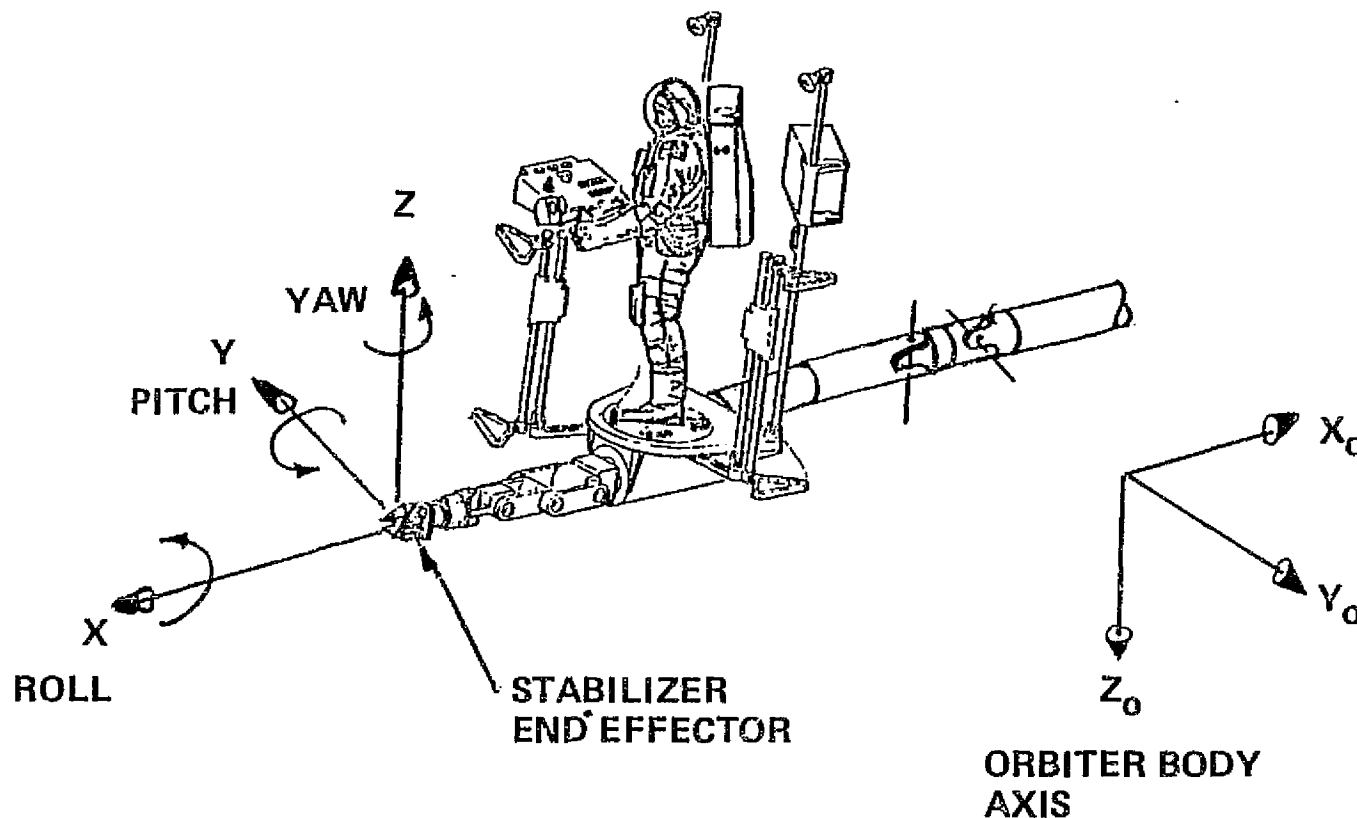


STABILIZER COORDINATE REFERENCE SYSTEM

A coordinate reference system for stabilizer motion when operated in the manual augmented mode by means of the Rotational and Translational Hand Controllers is shown on the opposite page. The roll axis is established by a center line through all the joint centers when they lie in the same plane and the center point of the end effector. Movement of the Translational Hand Controller causes translation of the end effector centerpoint along the axes shown (X, Y, Z) with no rotation. Movement of the Rotational Hand Controller causes rotation about the axes shown (X, Y, Z) with no translation. The hand controller signals are routed to the MDF computer which contain the equations of motion of the stabilizer and the computer command signals are routed to the stabilizer joints via the Stabilizer Power Control Center.

STABILIZER COORDINATE REFERENCE SYSTEM

- TRANSLATION CONTROL CAUSES TRANSLATION OF THE END EFFECTOR CENTER POINT ALONG THE AXES SHOWN (X, Y, Z)
- ROTATIONAL CONTROL IN PITCH, ROLL AND YAW CAUSES ROTATION OF THE END EFFECTOR CENTER POINT ABOUT THE END EFFECTOR X, Y, Z AXES RESPECTIVELY



ORIGINAL PAGE IS
OF QUALITY

GRUMMAN

HAND CONTROLLER CONFIGURATIONS

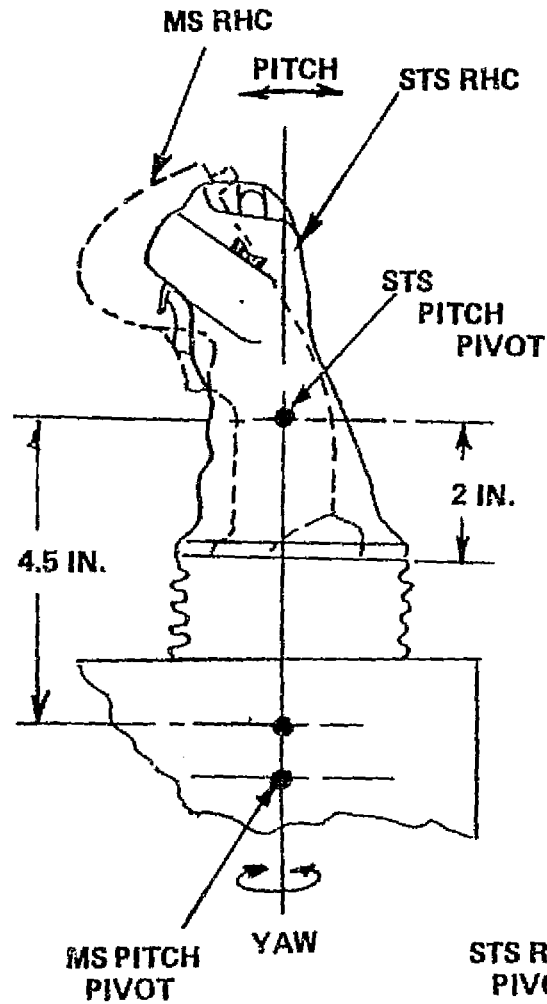
Using the Shuttle RMS operators hand controllers as a baseline, various hand controllers were investigated for use on the OCP-DTA. On the opposite page Rotational and Translational Hand Controllers, made by Measurement Systems Inc., are compared with the Shuttle controllers. For the Rotational Controllers, the hand grips are different and the switches are located in different positions on the grip. The yaw axes pivots coincide but the roll pivot axes are 0.64 inches apart; the pitch axes pivots are 5.14 inches apart.

For the Translation Hand Controller, the X axes coincide but the Y and Z axes are only 0.17 inches apart. The MS controller has a tee handle at the end of the shaft and the Shuttle has a small knob.

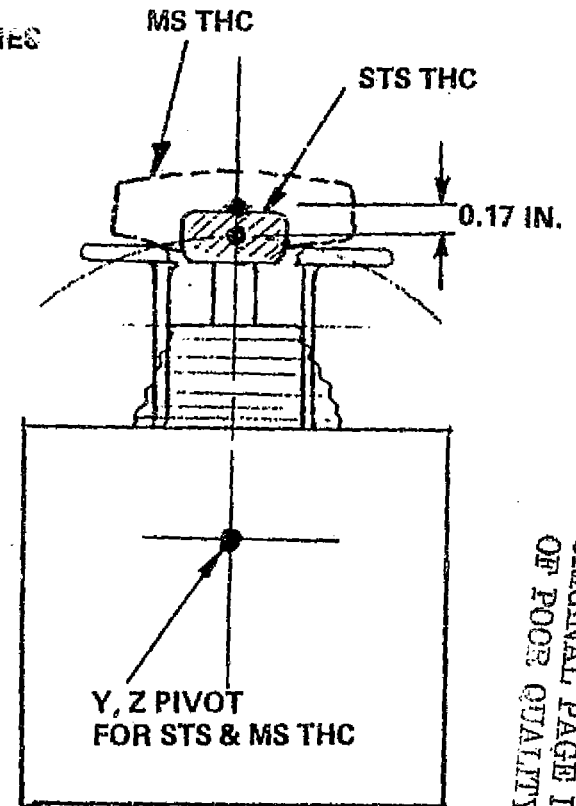
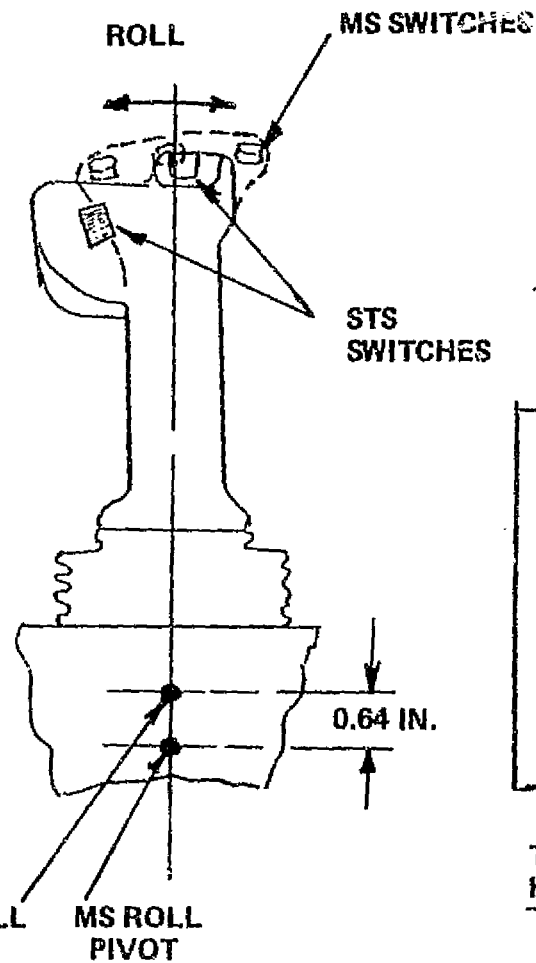
Further evaluation of modified MMU hand controllers will be made.

HAND CONTROLLER CONFIGURATIONS

- MS — MEASUREMENT SYSTEMS
- STS — SHUTTLE RMS CONTROLLERS



ROTATIONAL HAND CONTROLLER (RHC)



TRANSLATIONAL HAND CONTROLLER (THC)

ORIGINAL PAGE IS
OF POOR QUALITY



HAND CONTROLLER COMPARISON

The table shown on the opposite page compares the operational characteristic of the Shuttle RMS Hand Controllers and those made by Measurements System Inc. Although the basic MS models deflection, force gradient and null band are different from the Shuttle H.C., they can be varied to closely match the Shuttle H.C. The Shuttle THC contains viscous damping but only friction damping is available in the MS models. No information is available on the MS model breakout forces. The MS model RHC grips are not compatible with the EVA gloves, and there is some doubt whether the Shuttle RMS Controllers are EVA compatible.

HAND CONTROLLER COMPARISON

| | SHUTTLE RMS H. C. | | MEASUREMENT SYSTEM INC | |
|---|-------------------|------------------|---|-----------------------------------|
| | RHC | THC | RHC (MODEL 544) | THC MODEL 544-G423 |
| • DEFLECTION | | | | |
| PITCH, ROLL, YAW (DEG) | ±14, ±14, ±10 | | ±28, ±28, ±28 (CAN BE VARIED) | |
| X, Y, Z (IN ARC) | | ±.55, ±.95, ±.95 | | ±5, ±2.6, ±2.6 (CAN BE VARIED) |
| • FORCE GRADIENT | | | | |
| PITCH, ROLL, YAW ($\frac{\text{IN.-LB}}{\text{DEG}}$) | 0.6, 0.82, 0.52 | | 0.68, 0.68, 0.13 | |
| X, Y, Z (LB/IN.) | | 0.84, 0.31, 0.31 | (CAN BE VARIED) | (CAN BE VARIED FROM 0.2 - 2.4) |
| • BREAKOUT FORCE | | | | |
| PITCH, ROLL, YAW (IN.-LB) | 2, 4, 3 | | ----- | |
| X, Y, Z (LB) | | 1, 0.65, 0.65 | | ----- |
| • DAMPING | | | FRICTION | |
| X, Y, Z ($\frac{\text{LB-SEC}}{\text{IN.}}$) | NONE | 0.44, 0.20, 0.20 | | FRICTION |
| • NULL DEADBAND | | | | |
| PITCH, ROLL, YAW (DEG) | ±.25, ±.25, ±.25 | | ±2.5, ±2.5, ±2.5 (CAN BE DE- CREASED) | |
| X, Y, Z (IN.) | | ±.01, ±.01, ±.01 | | ----- |
| • ELECTRICAL | RESOLVER | RESOLVER | D. C. POT | D. C. POT |
| • SWITCHES | 3 | NONE | 4 | NONE |
| • GRIP EVA COMPATIBILITY | ? | ? | NO | NO |
| • COST & DELIVERY | ? | ? | \$2044-10 WKS | \$5308-14 WKS |

BRUMMAN

ELECTRICAL SUBSYSTEM DESIGN ISSUES AND SIMULATION APPROACH

To investigate the electrical subsystem technical issues, the D&C panel of the DTA will be constructed in a modular fashion to facilitate field updates. The technical issues are basically what is the best way to implement the design of the man-machine interface in a direct sun impingement environment.

The flight harness design and routing will be developed with a combination of analysis and environment testing. The functional testing of the chosen concept will be performed on the DTA in the last quarter of simulation testing to validate the concept.

ELECTRICAL SUBSYSTEM DESIGN ISSUES AND SIMULATION APPROACH

DIRECT SUN IMPINGEMENT ON PANEL

- LAMP VS FLAG
- EDGE LITE VS ELECTROLUM PANEL
- SHIELDED ANNUNCIATORS
- SUNSCREEN

HYBRID PNL/FIELD UPDATE AS NECESSARY

DEXTERITY ISSUES (GLOVED HAND)

- PUSH BUTTON VS TOGGLE SWITCH
VS ROTARY
- STAB DIRECT DRIVE SW'S
- ASTRONAUT FUNCTIONS

HYBRID PNL/FIELD UPDATE

HAND CONTROLLERS

- MAN MACHINE I/F

DESIGN ADAPTABLE DTA I/F

WIRE HARNESS AROUND ROTATING JOINTS IN COLD SOAK ENVIRONMENT

- LOCAL HEATERS
- WIRE COIL
- KAPTON RIBBON CABLE
- SLIP RINGS

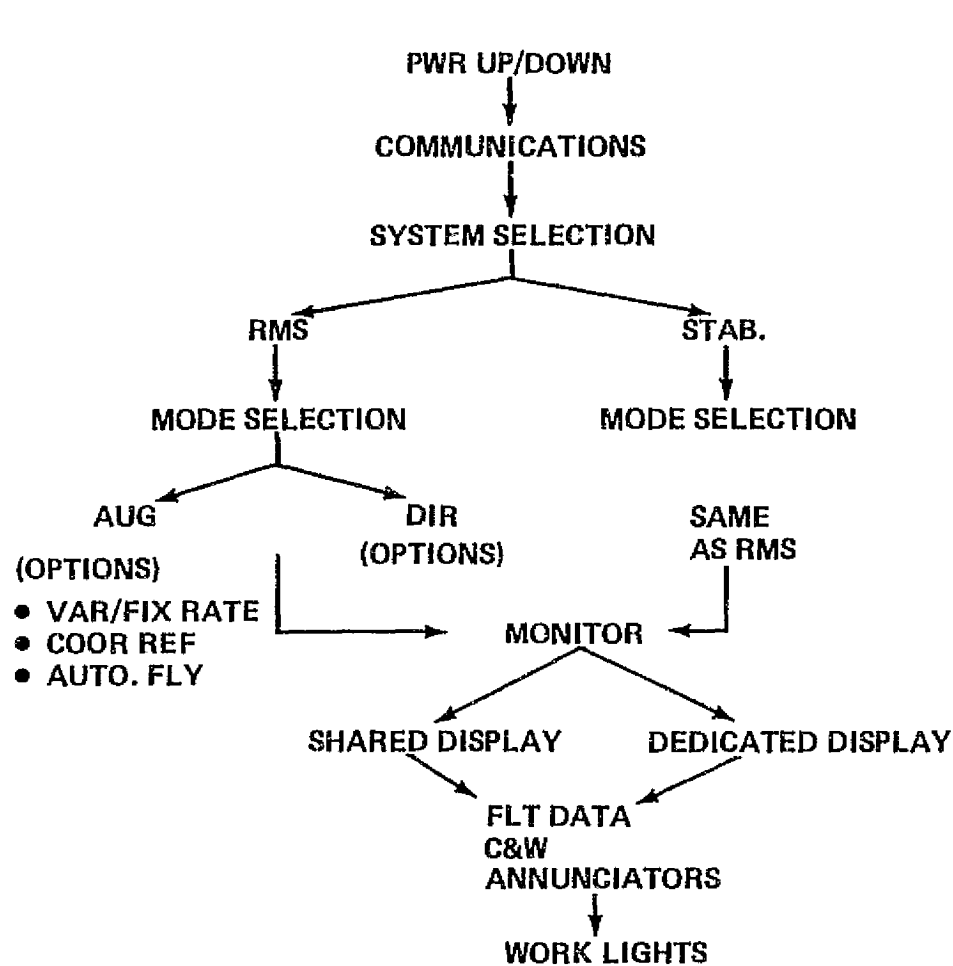
ANALYSIS AND ENVIRONMENT TESTING



OCP D&C FUNCTIONAL LOGIC TREE

The functional logic tree was developed from the mission operational requirements. Its purpose is to diagram the functional options available to the astronaut and as such define the functional requirements to which the D&C electrical subsystem will be designed. The ballooned notes are the implementation options available to the designer. The designer options are driven by the environment and man-machine requirements that the D&C must also meet and are considered the technical issues of the design. Both the functional options, available to the astronaut, and the technical issues, available to the designer, will be the subjects of simulation development testing.

OCP D&C FUNCTIONAL LOGIC TREE



DESIGN OPTIONS

SWITCH'S

- PUSHBUTTON
- TOGGLE
- ROTARY

CONTROLLERS:

- DOF
- SINGLE/MULTI-AXIS
- DISCR/PROPORTIONAL

- LAMP VS FLAG
- INTEGRAL LIGHT PANEL



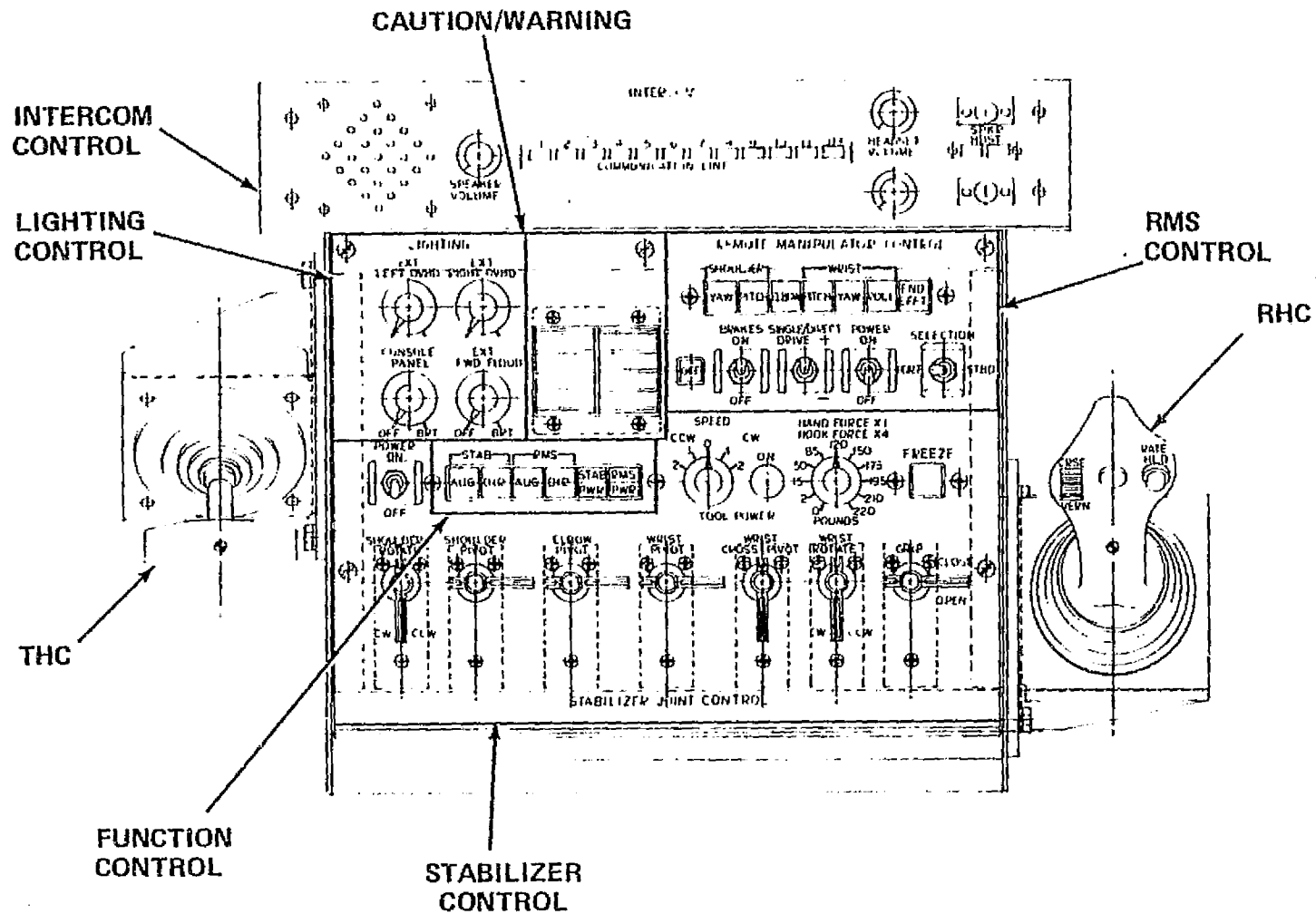
DISPLAY/CONTROL CONSOLE

The next four charts show the layout of the PDR baseline design. The numbered balloons refer to the element part numbers and functional descriptions annotated in the accompanying charts.

The panel has been sectorized into six (6) functional areas, namely:

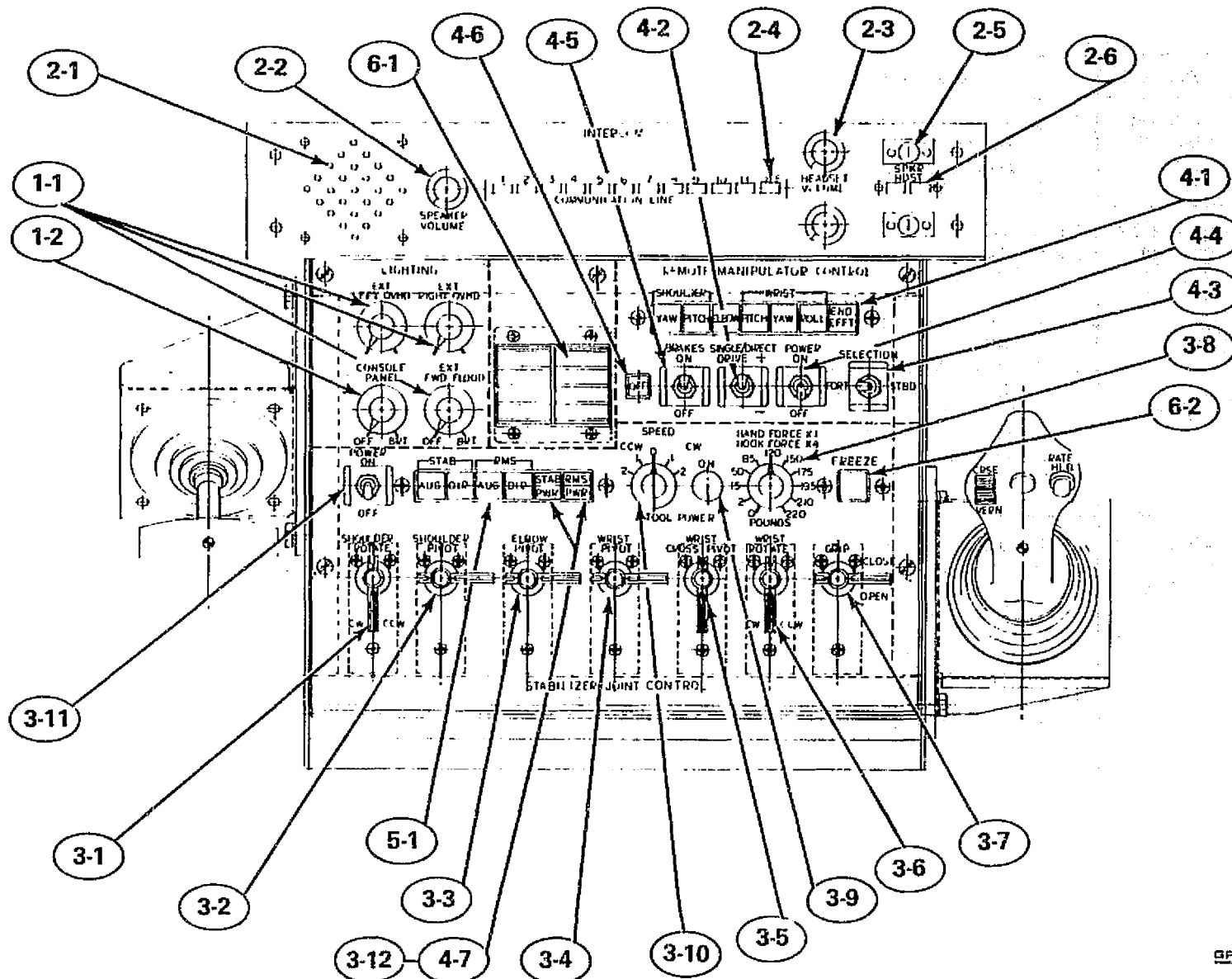
- Lighting control
- Intercom control
- Stabilizer control
- Remote manipulator control
- Function control
- Caution and warning

DISPLAY/CONTROL CONSOLE



ORIGINAL PAGE IS
OF POOR QUALITY

CONTROLS/DISPLAY CONSOLE ARRANGEMENT



ORIGINAL PAGE IS
OF POOR QUALITY

CONTROLS/DISPLAY CONSOLE ARRANGEMENT (CONTD)

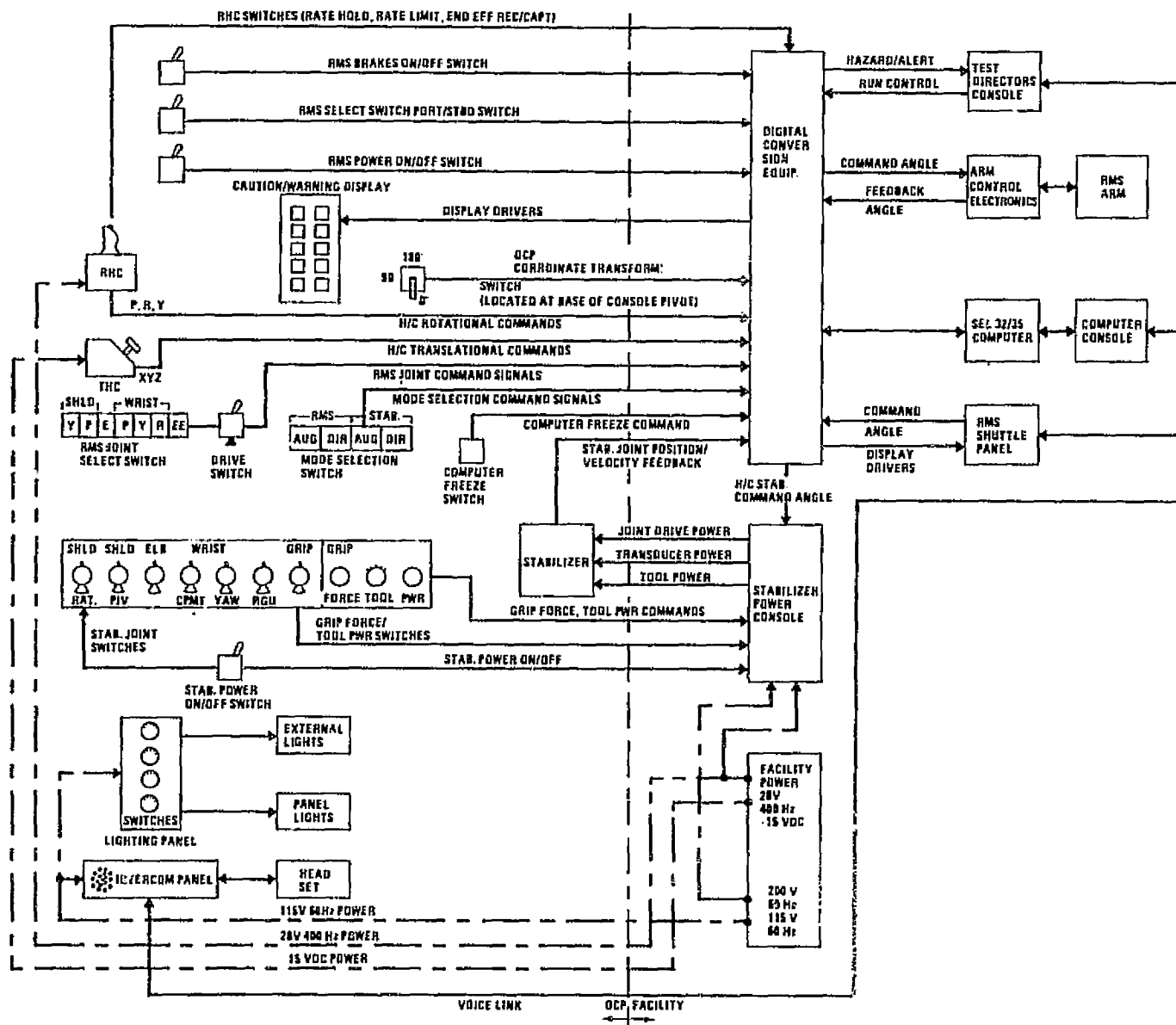
| SECTION | ELEMENT PART NO. | FUNCTION |
|-----------------------------|---|---|
| 1) LIGHTING CONTROL | 1-1 (3) THREE CONTINUOUSLY VARIABLE ROTARY SWITCH 1-2 CONTINUOUSLY VARIABLE ROTARY SWITCH | FLOODLIGHTS, ON/OFF & BRIGHTNESS CONTROL PANEL/ANNUNCIATOR LIGHTS, ON/OFF & BRIGHTNESS CONTROL |
| 2) INTERCOM CONTROL | 2-1 SPEAKER 2-2 CONTINUOUSLY VARIABLE ROTARY SWITCH 2-3 (2) TWO CONTINUOUSLY VARIABLE ROTARY SWITCHES 2-4 (11) ELEVEN PUSH-BUTTON ON SWITCHES AND (1) ONE OFF SWITCH 2-5 (2) TWO HEADSET JACKS 2-6 (2) TWO PUSHBUTTON SWITCHES | SPEAKER VOLUME CONTROL HEADSET VOLUME CONTROL SELECT CHANNEL FOR POINT TO POINT COMMUNICATION FOR PLUGGING HEADSETS WITH PRESS-TO-TALK SWITCH ON CORD INTO PANEL FOR ACTIVATING PANEL SPEAKER INSTEAD OF HEADSETS |
| 3) STABILIZER JOINT CONTROL | 3-1 THRU 3-7 3 POSITION SWITCHES, SPRING RETURN TO CENTER OFF, CONTINUOUSLY VARIABLE OUTPUT IN EACH DIRECTION 3-8 CONTINUOUSLY VARIABLE ROTARY SWITCH 3-9 ROTARY ON/OFF SWITCH 3-10 (5) FIVE POSITION ROTARY SWITCH 3-11 TWO POSITIONS SWITCH 3-12 ANNUNCIATOR LIGHT | EACH SWITCH CONTROLS VELOCITY AND DIRECTION OF MOTION OF INDIVIDUAL STABILIZER JOINTS; VELOCITIES IN EACH MOTION DIRECTION IS PROPORTIONAL TO DISPLACEMENT OF SWITCH FROM CENTER POSITION ADJUST GRIP FORCE POWER FOR TOOLS SELECT 2 SPEED REVERSIBLE CONTROL OF 115 VOLT AC/DC UNIVERSAL MOTORS UP TO ½ HP SELECT POWER ON/OFF INDICATES POWER ON |



OCP/MDF ELECTRICAL INTERFACE SCHEMATIC

This functional schematic depicts the handcontrollers, facility power distribution, communications network, six functional areas of D&C, facility computer system, and test consoles. The center dashed line indicates the OCP to MDF interface point.

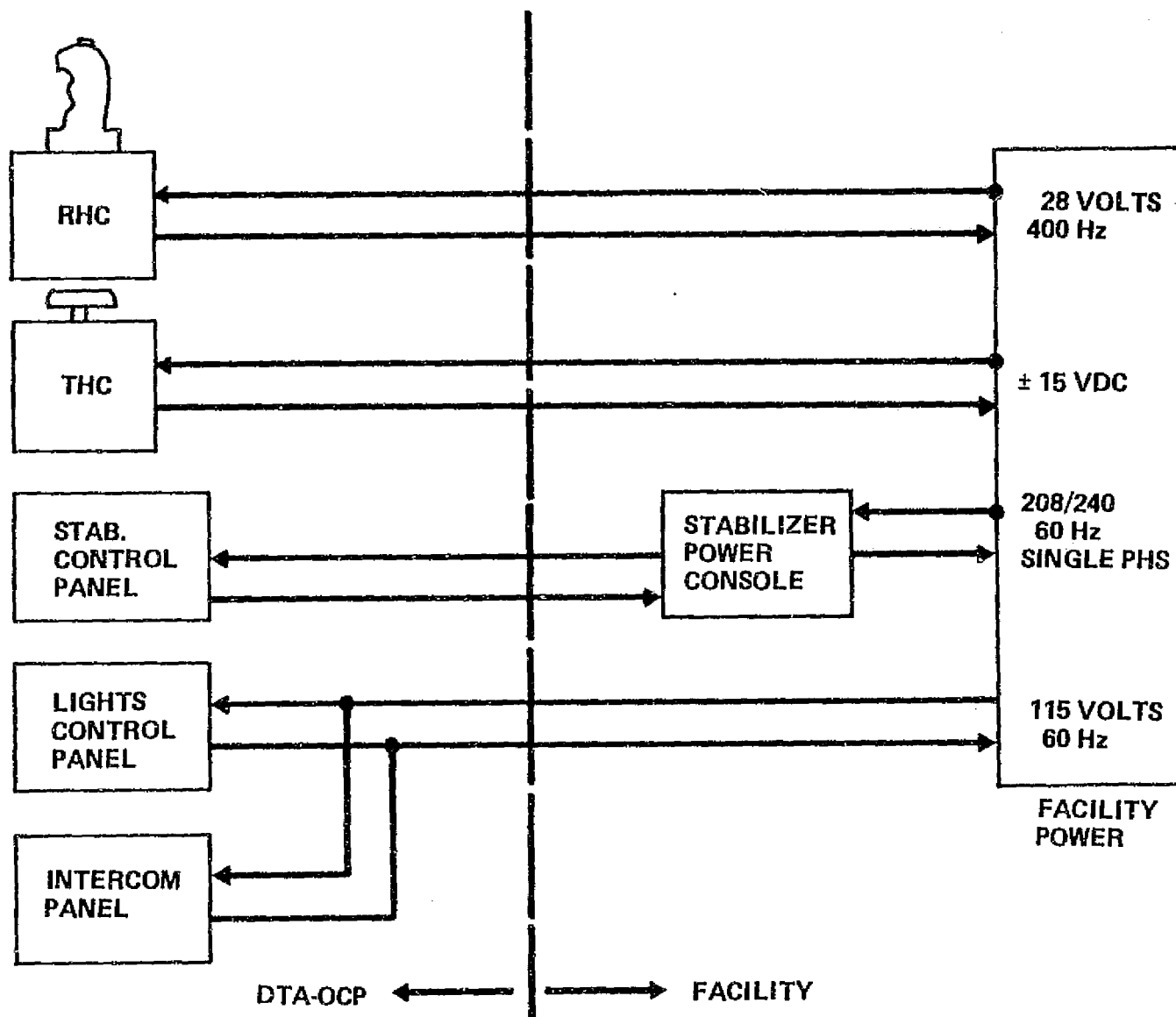
OCP/MDF ELECTRICAL INTERFACE SCHEMATIC



POWER SYSTEM

This functional schematic depicts the facility primary power distribution to the OCP electrical subsystem elements.

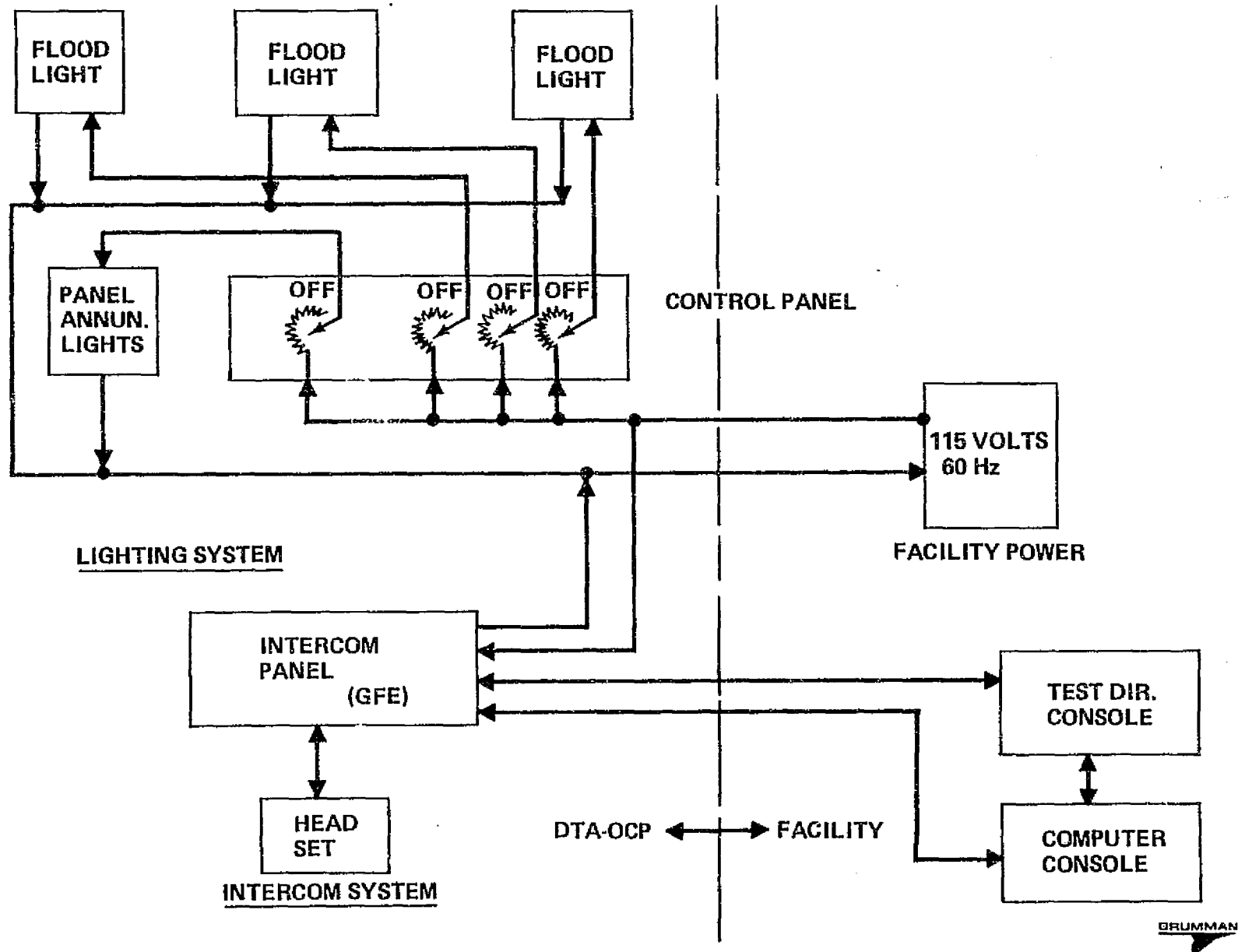
POWER SYSTEM



LIGHTING AND INTERCOM SYSTEM

This functional schematic depicts the work light, D&C panel/annunciator lighting controls, and distribution. It also depicts the laboratory communications network distribution.

LIGHTING AND INTERCOM SYSTEM

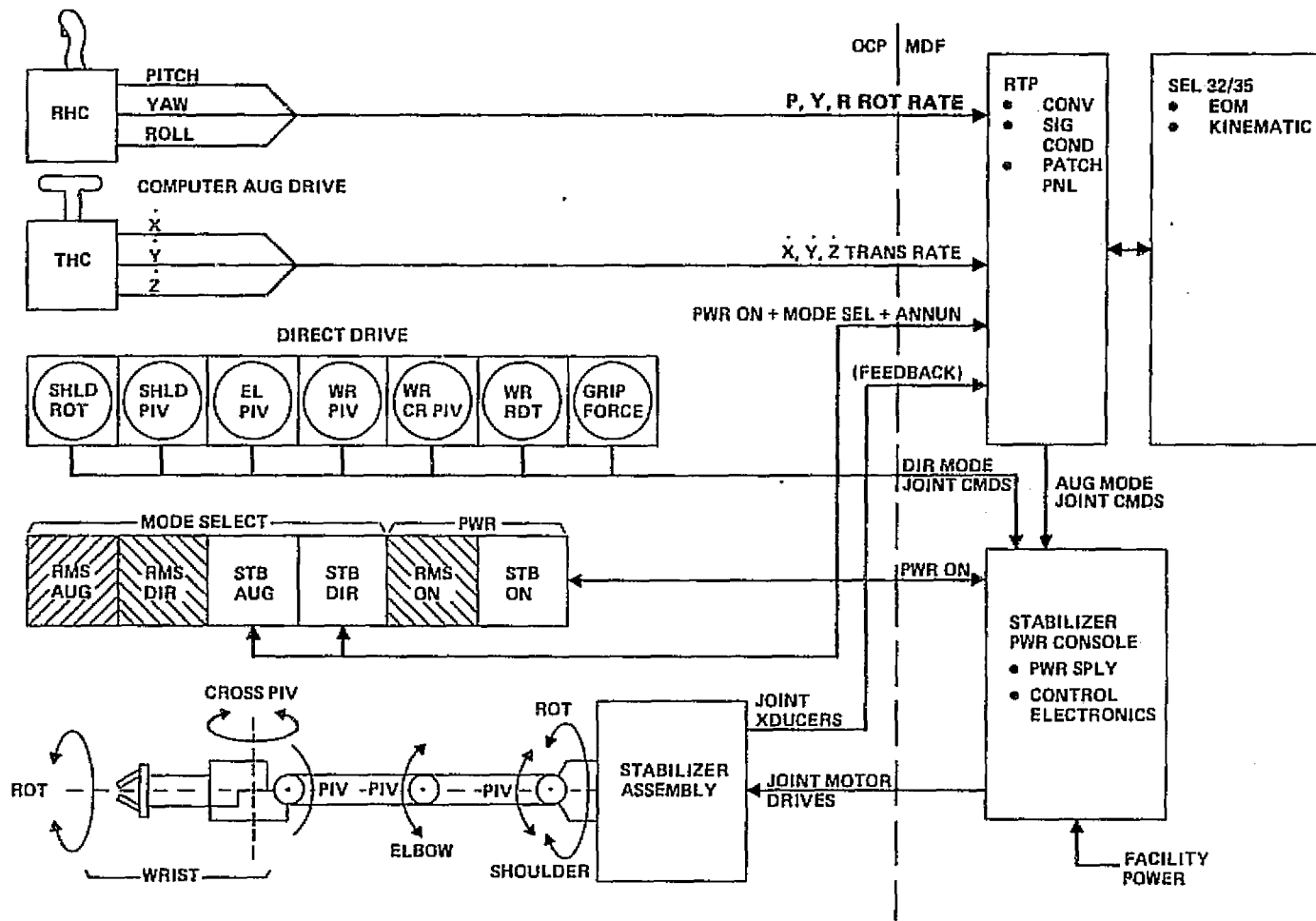


STABILIZER SUBSYSTEM

This functional schematic depicts the primary signal paths for all Stabilizer subsystem functions, namely:

- STABILIZER PWR ON/OFF
- MODE SELECTION STB AUG/STB DIR
- STB AUG: RHC & THC selected to input 6 DOF rate commands to the MDF computer (SEL 32/35) through the input/output interface unit (RTP). The computer contains the stabilizer equations of motion and calculates resolved rate stabilizer joint commands. The joint commands are transmitted to the interface unit and from there to the stabilizer power console.
- STB DIR: Direct drive, variable rate commands for each joint can be singularly/multiple selected to bypass the FLT computer and drive the stabilizer power console directly.
- STAB PWR CONSOLE: Contains the stabilizer power supply and control electronics. The input joint commands from either the AUG/DIR controllers are converted to joint motor drive commands which are hardwired to their respective joint motors on the stabilizer assembly. Each joint motor servo has tachometer and position feedback devices which are transmitted to the MDF computer for all resolved rate computations. Direct drive mode is a variable rate open loop drive system.

STABILIZER SUBSYSTEM

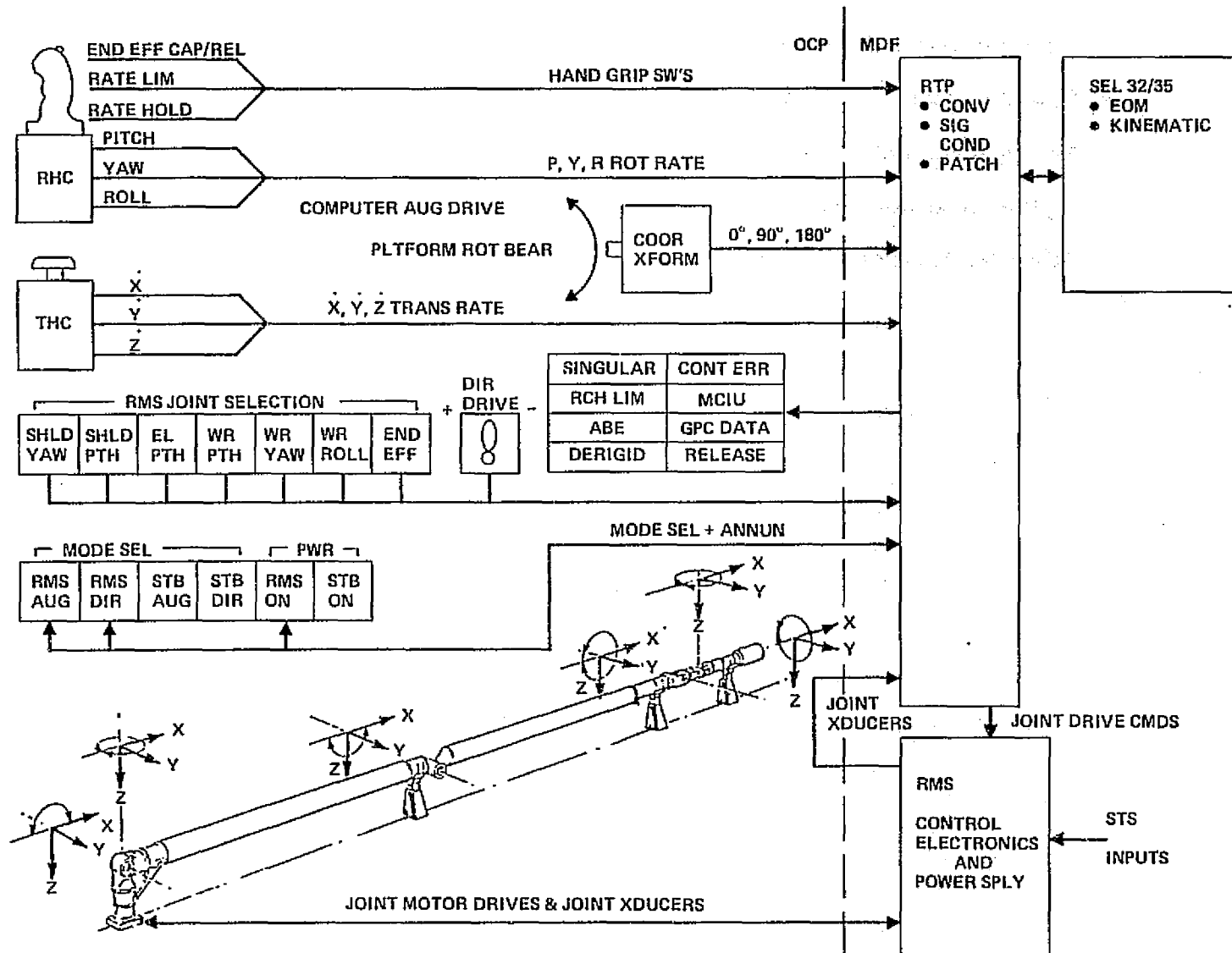


RMS SUBSYSTEM

This functional schematic depicts the primary signal paths for all DCP directed RMS subsystem functions, namely:

- RMS PWR ON/OFF
- MODE SELECTION RMS AUG/RMS DIR
- RMS AUG: RHC & THC selected to input 6 DOF rate commands to the MDF computer (SEL 32/35) through the input/output interface unit (RTP). The computer contains the RMS equations of motion and dynamics for resolved rate RMS joint command computations. The joint commands are transmitted to the RTP and from there to the RMS control electronics unit.
- RMS DIR: Direct drive, constant rate commands for each joint can be singularly selected. The single axis controller is routed to the MDF computer via the RTP interface unit. The computer calculates single axis joint drive commands which are transmitted to the RMS control electronics via the RTP interface unit. During direct drive the computer controls the individual joint breaks, set/release, as appropriate.
- RMS CONTROL ELECTRONICS: Contain the power supplies and control electronics. The control electronics drive each joint motor individually. Each joint motor has a tachometer and position feedback device which is fed back to the MDF computer for resolved rate computations.
- COORDINATE TRANSFORMATION SW: Activated by D&C pedestal position to permit "fly to" control from the $0^{\circ}/90^{\circ}/180^{\circ}$ D&C pedestal positions.
- BREAK SWITCH: Manually sets/release RMS joint motor breaks.
- CAUTION:& WARNING: MFD computer driven C&W indicators.

RMS SUBSYSTEM



MDF RTP I/F REQUIREMENTS SUMMARY

This table contains the preliminary estimates for:

- Discrete input data to the MDF computer
- Discrete output data from the MDF computer
- Analog-to-digital converters (contains EST for stab. feedback)
- Digital-to-analog converters
- OCP wire harness estimate.

MDF RTP I/F REQUIREMENTS SUMMARY

| | |
|---------------------|--------------------------------------|
| • DISCRETE INPUT | 24 |
| • DISCRETE OUTPUT | 22 |
| • ANALOG TO DIGITAL | 18 (CONTAINS EST. FOR RESOLVED AXIS) |
| • DIGITAL TO ANALOG | 8 |

CABLING ESTIMATION

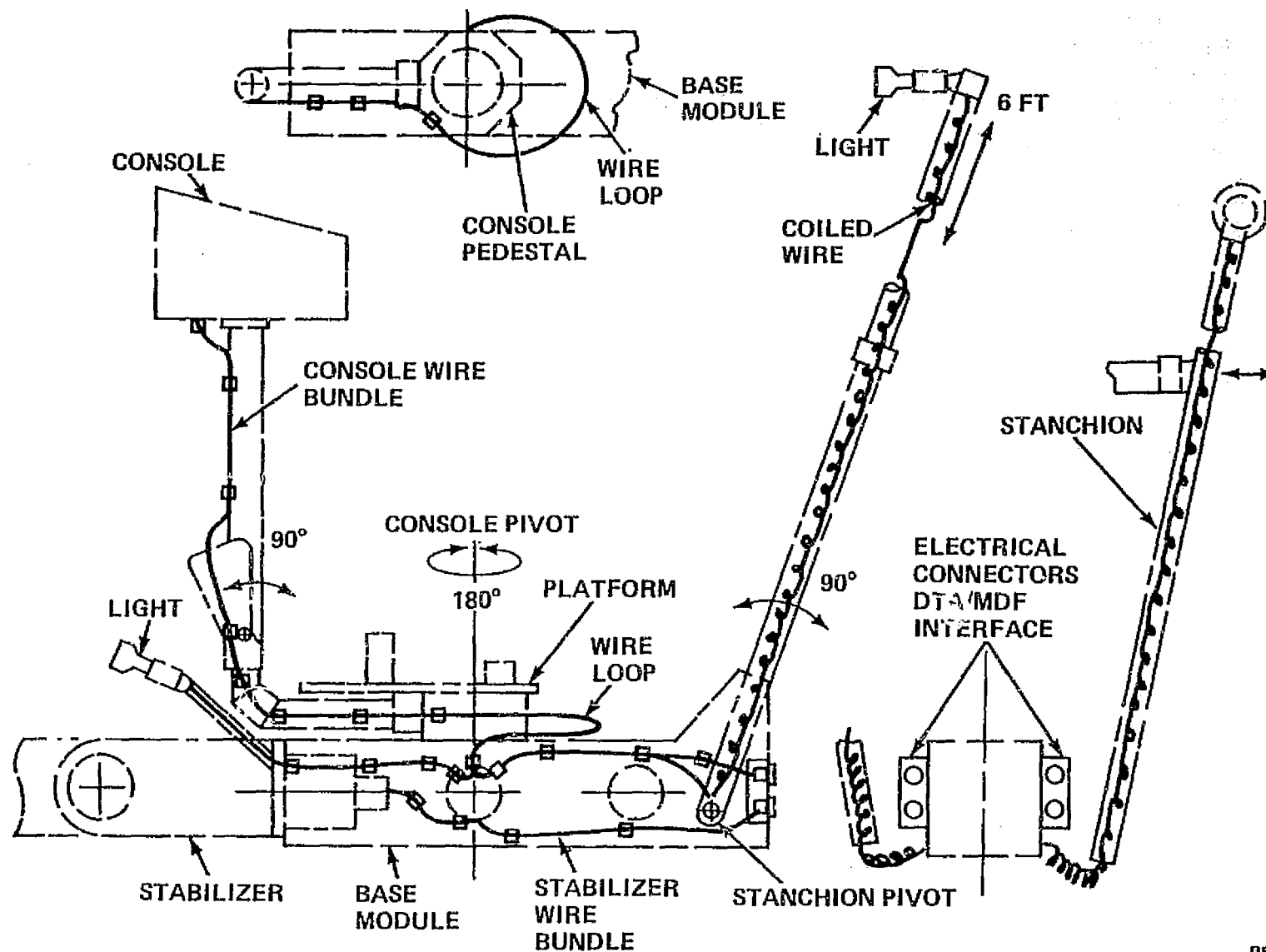
| | |
|------------------------|--------------|
| • RHC | 16 WIRE |
| • THC | 12 WIRE |
| • STABILIZER | 30 WIRE |
| • INTERCOM | TBD (50 EST) |
| • RMS | 24 WIRE |
| • FUNCTION CONTROL | 16 WIRE |
| • C&W | 9 WIRE |
| • FREEZE & COOR TRANS. | 9 WIRE |



OCP ELECTRICAL WIRE ROUTING

A diagrammatic presentation of the OCP wire harness for the D&C console and work lights is shown on the facing page. The diagram depicts the proposed method of accommodating the DTA articulated structural elements. The MDF ICD point will be a series of back plane connectors located on the DTA/MDF interface plane.

OCP ELECTRIC WIRE ROUTING



ORIGINAL PAGE IS
OF POOR QUALITY

GRUMMAN

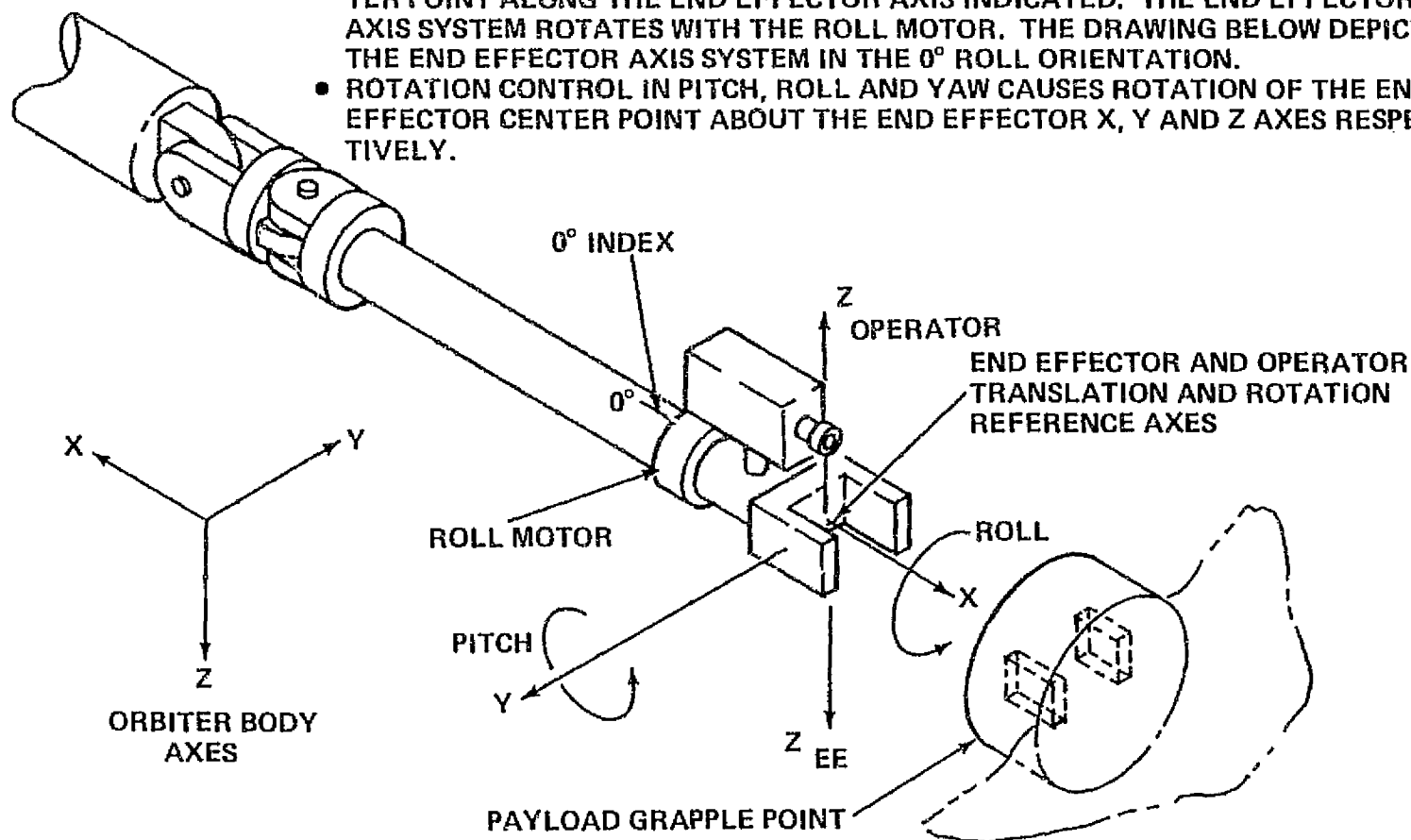
RMS-MDF COORDINATE REFERENCE SYSTEM

An existing coordinate reference system for the RMS-MDF as shown on the opposite page will be used when the MDF-RMS is operated in the manual augmented mode by means of the Rotational and Translational Hand Controllers located on the OCP-DTA. Movement of the Translational Hand Controller causes translation of the end effector center point along the end effector axis indicated with no rotation. The end effector axis system rotates with the roll motor. Movement of the Rotational Hand Controller causes rotation about the axes shown with no translation. Since the OCP-DTA will be operating on the MDF airbearing floor, movement of the hand controllers will only produce translational motion in the X and Y directions and rotation about the Z axis.

RMS-MDF COORDINATE REFERENCE SYSTEM

END EFFECTOR REFERENCED

- TRANSLATION CONTROL CAUSES TRANSLATION OF THE END EFFECTOR CENTER POINT ALONG THE END EFFECTOR AXIS INDICATED. THE END EFFECTOR AXIS SYSTEM ROTATES WITH THE ROLL MOTOR. THE DRAWING BELOW DEPICTS THE END EFFECTOR AXIS SYSTEM IN THE 0° ROLL ORIENTATION.
- ROTATION CONTROL IN PITCH, ROLL AND YAW CAUSES ROTATION OF THE END EFFECTOR CENTER POINT ABOUT THE END EFFECTOR X, Y AND Z AXES RESPECTIVELY.



ORIGINAL PAGE IS
QUALITY

DTA SOFTWARE REQUIREMENTS

This table contains a functional breakdown and proposed format of the additional MDF software required to perform OCP simulation studies.

DTA SOFTWARE REQUIREMENTS

1. MDF RMS SOFTWARE – ALL MODES (NASA)
2. OCP RMS SOFTWARE INTERFACE TO MDF RMS PKG #1 (GAC)
 - INITIALIZATION
 - HANDOVER LOGIC
 - INTERFACE TO HARDWARE (OCP)
3. OCP STABILIZATION SOFTWARE (GAC)
 - CONTROL LOGIC – RESOLVED RATE MODE
 - INITIALIZATION
 - EQUATIONS AND ALGORITHM
 - INTERFACE TO HARDWARE (OCP & STABILIZER)
4. DELTA SOFTWARE PACKAGE FORMAT AND ESTIMATE
 - MATH MODELS: EQUATIONS & ALGORITHM
DEF OF VARIABLES
INITIAL CONDITIONS
CHECK CASE (OPEN LOOP)
 - SOFTWARE: FLOW CHARTS
CODING
COMPILE FORTRAN – SEL 32/35
TEST
5. INTEGRATION & CHECKOUT AT MDF



SIMULATION TEST PLAN MATRIX

This table presents the elements from which the OCP simulation test procedures and test plans will be developed during the next phase of the contract. The matrix contains three categories of test elements:

- Work articles
- Work tasks
- Things to be evaluated (outputs of the tests).

SIMULATION TEST PLAN MATRIX

| WORK ARTICLES | WORK TASKS | EVALUATE |
|---|---|--|
| <ul style="list-style-type: none"> • BEAM/TRUSS • PANELS • TENSION CABLE/TAPE • ELECTRIC CABLE/BUS • MICROWAVE PLUMBING • FLUID/GAS LINES • HARDWARE COMPONENTS • SOLAR BLANKETS • SUPPORT EQUIP. <ul style="list-style-type: none"> – TOOLS – MONITOR & C/O INSTR. – WELDER – BEAM BUILDER | <ul style="list-style-type: none"> • LG. STRUCTURE CONSTRUCTION <ul style="list-style-type: none"> – ACTIVATION – UNSTOW/STOW MATERIAL – TRANSPORT – GRAPPLE/STAB. (CAPTURE) – PAYLOAD HANDLING – ALIGN – FASTEN/ATTACH – ADJUST/ALIGN – MONITOR/CHECKOUT – CLEANUP – DISENGAGE • LG. STRUC. CONSTR. MAINTENANCE <ul style="list-style-type: none"> – SSAFE – LSS • SATELLITE SERVICING <ul style="list-style-type: none"> – MMS – LST – LDEF • RESCUE | <ul style="list-style-type: none"> • OCP DESIGN • SYSTEM I/F • MAN-MACHINE I/F • ASTRONAUT PROCEDURES <ul style="list-style-type: none"> – TIMELINES • METABOLIC WORKLOAD <ul style="list-style-type: none"> – EFFICIENCY • SUPPORT EQUIP. ROOMS <ul style="list-style-type: none"> – TOOLS – MONITOR/CKOUT INST – CONSTRUCTION EQUIP <ul style="list-style-type: none"> o BEAM BUILDER o WELDER o CRANE |



SIMULATION IMPLEMENTATION OBJECTIVES

To implement the simulation objectives and develop test plan/procedures, we must:

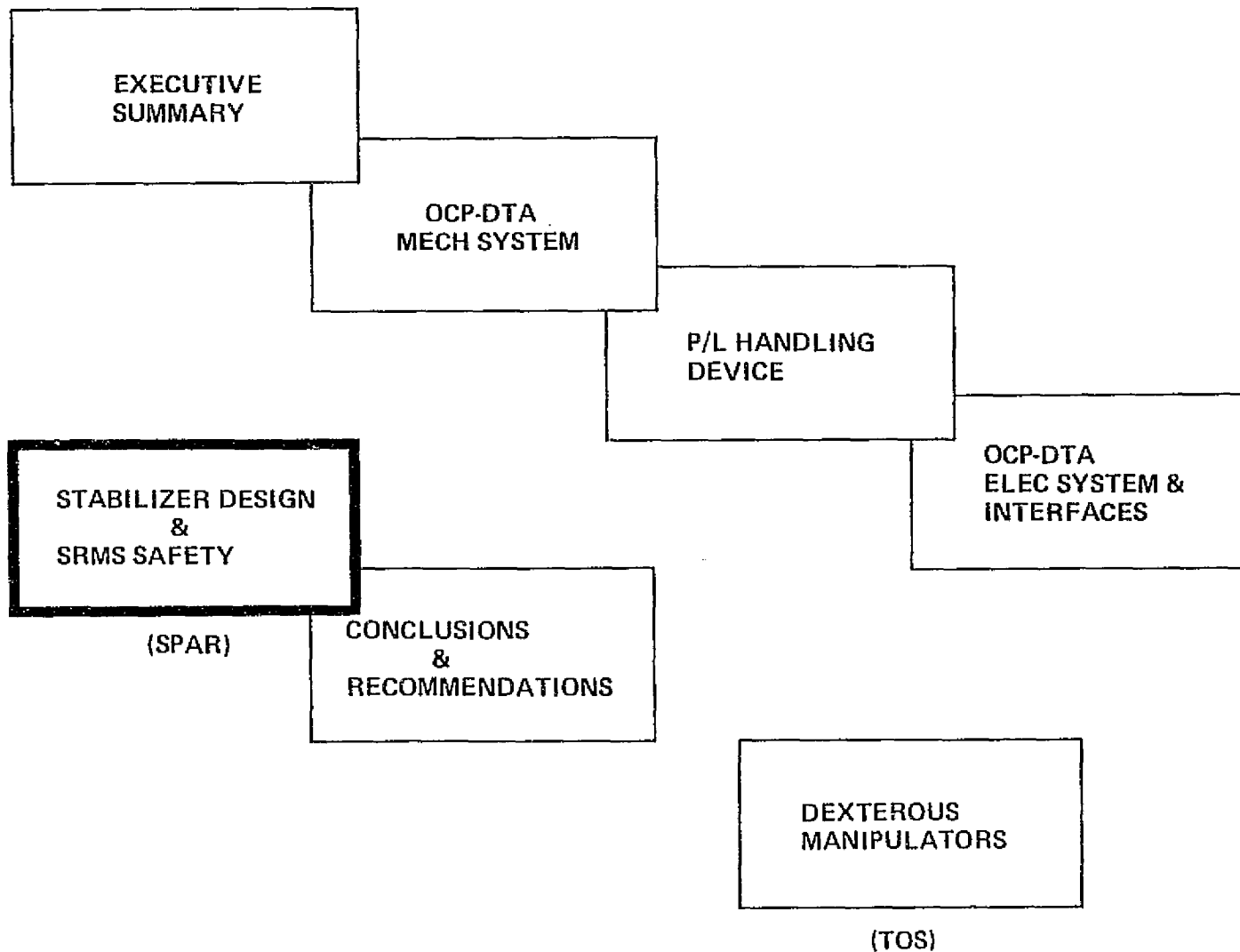
- Analyze satellite servicing and construction requirements to define work articles, test procedures, and define test support equipment requirements
- Evaluate work article requirements to increase the mission environment relative degrees-of-freedom
- Evaluate special tools and procedures of EVA quality in order to conduct mission scenario simulations.

TO IMPLEMENT THE SIMULATION OBJECTIVES

WE NEED:

- SATELLITE SERVICING AND CONSTRUCTION REQUIREMENTS
- ARTICULATED WORK ARTICLES (6 DOF RELATIVE)
- SPECIAL TOOLS AND PROCEDURES (EVA QUAL)





PRELIMINARY SAFETY ASSESSMENT

The opposite page shows the assumptions that have been made when assessing the safety of the SRMS with a man mounted at the end. It must be stressed that the probability of any failure is small, but they must all be considered.

The assumptions are:

- Only single case failures are considered
- At all times that an astronaut is in the OCP, the Aft cabin control station will be manned
- Effects of failures are only considered when the astronaut is mounted on the OCP
- If the orbiter is in automatic stationkeeping, then the thrusters must be inhibited during operation of the MRWS
- If a failure occurs then the first action will be to apply the brakes and bring the arm to rest
- The next step is to select the lower level of control.

PRELIMINARY SAFETY ASSESSMENT

ASSUMPTION

- SINGLE FAILURES ONLY
- OPERATOR IN AFT CABIN
- FAILURES PRIOR TO ASTRONAUT MOUNTING OCP NOT CONSIDERED
- FAILURES AFTER ASTRONAUT DISMOUNTS FROM OCP NOT CONSIDERED
- ORBITER THRUSTERS INHIBITED
- WHEN FAILURE OCCURS BRAKES APPLIED
- REVERT TO NEXT LEVEL OF CONTROL



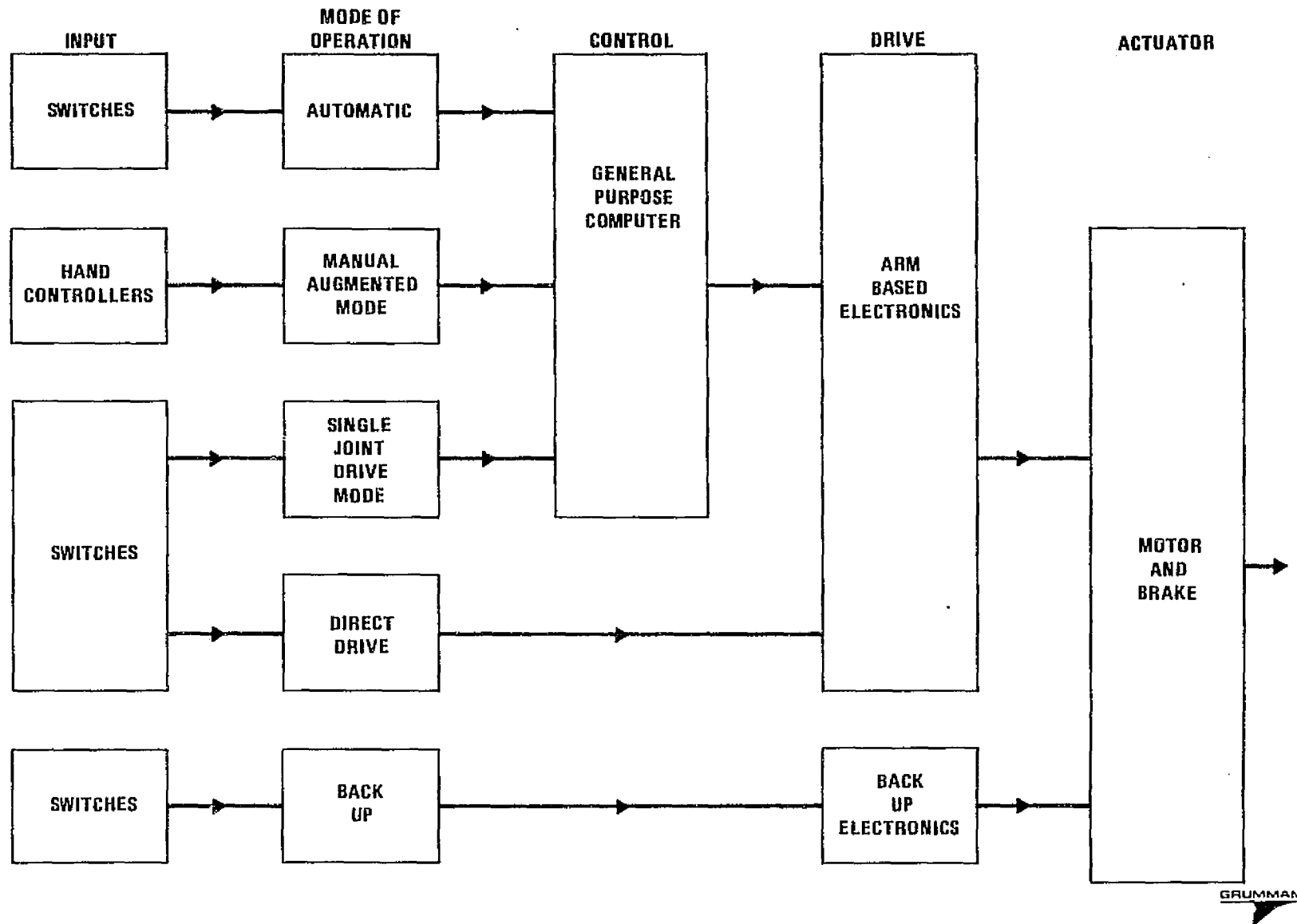
CONTROL HIERACHY

The opposite page shows the control hierachy of the SRMS.

- In the Automatic mode the operator selects from within a software package of pre-determined trajectories or defines to the control algorithms the trajectory the end effector is to follow in terms of end effector position and attitude.
- In Manual Augmented mode the human operator uses the rotational and translational hand controllers to provide end effector rotational and translational velocity demands to the control algorithms.
- In Single Joint Drive mode the operator provides a fixed drive signal to the control algorithms, which in turn provide a rate command to the servo being driven, dependent upon operating conditions.
- Direct Drive mode is a contingency drive mode by-passing the GPC by enabling the operator to provide a direct drive command to the Arm Based Electronics via hardwires. Since this is a contingency mode of operation full joint performance characteristics are not available as they are only in software supported drive modes.
- Back-Up Drive mode is a contingency drive mode used when no Prime Channel drive mode is available, enabling degraded joint-by-joint performance. Back-Up Drive is designed to fulfill the fail-safe requirement of the SRMS by using only the drive train of the Prime Channel bypassing the rest of the system.

If a failure occurs in the system then a lower level of control can be selected.

CONTROL HIERARCHY



UNSAFE CONDITIONS

The opposite page shows the conditions which are considered unsafe to the astronaut in the OCP.

This information has been obtained by reviewing the following reports:

- SPAR-TM, 1497 - "SRMS System Hazard Analysis"
- SPAR-TM, 1452 - "SRMS Failures Mode Effects Analysis"

UNSAFE CONDITIONS

- INADVERTENT RELEASE OF PAYLOAD (JETTISON ASTRONAUT)
- UNCONTROLLED MOTION
- LOSS OF ABILITY TO DRIVE OR STOP JOINT (STRANDING ASTRONAUT)



INADVERTENT RELEASE

Release of the OCP grapple Fixture by The SRMS End Effector

This may be caused by failure in the End Effector Electronic Unit or mechanical failure within the end effector. Design is such to minimize these faults occurring.

If this fault does occur then the first result will be that the electrical interface between the OCP and SRMS will be broken and the OCP astronaut will lose all control. The orbiter astronaut will be aware that this has happened because the alarm system will take over control. The grapple fixture on the OCP is then released completely by the end effector. This will result in the jettisoning of the OCP and the astronaut.

To prevent this possibility, it is suggested that additional straps be attached between the end effector and the OCP or attach a lifeline between the orbiter and the OCP.

INADVERTENT RELEASE

- POSSIBLE CAUSES

- END EFFECTOR COMMAND FAILURE
- END EFFECTOR ELECTRONIC UNIT FAILURE
- CAPTURE/RELEASE FAILURE
- RIGIDIZE/DERIGIDIZE FAILURE

- CONSEQUENCES

- ELECTRICAL INTERFACE BROKEN. CP OPERATOR LOSES ALL CONTROL
- OCP MAY BE RELEASED

- POSSIBLE ACTIONS

- PROVIDE ADDITIONAL STRAP BETWEEN ARM AND OCP
- PROVIDE LIFELINE BETWEEN ORBITER AND OCP



UNCONTROLLED MOTION

Motion of The Arm Which Is Not The Result of A Command Signal

This may be caused by a hand controller failure, a failure in a joint motor control loop or a structural failure such as the motor shaft or brake quill shaft breaking.

The result of this could be a collision with the orbiter or with the payload (the possibility of a collision being higher the closer the OCP is to either the orbiter or the payload).

To safeguard the astronaut should a collision occur, it is suggested that the OCP be constructed in such a manner to provide a protective cage for the astronaut.

UNCONTROLLED MOTION

- POSSIBLE CAUSES
 - HAND CONTROLLER FAILURE
 - MOTOR CONTROL LOOP FAILURE
 - MOTOR SHAFT OR BRAKE QUILL SHAFT FAILURE
- CONSEQUENCES
 - POSSIBILITY OF COLLISION (INCREASES THE CLOSER TO PAYLOAD OR ORBITER)
- POSSIBLE ACTIONS
 - PROVIDE PROTECTIVE CAGE FOR ASTRONAUT



STRANDING

The Arm May Not Be Able To Return The Astronaut To The Orbiter.

Possible causes for this may be brakes failing on, power supply failure, or motor failure. If only one joint fails it may be still possible to restore the astronaut to the orbiter using the other joints; however, if this cannot be achieved, it will be necessary to be able to retrieve the astronaut. This can be achieved by adding hand rails to the arm. These were considered in the early stages of SRMS but the decision was made not to include them. A hand hold is attached to the end effector. Another possibility would be to provide a tether between the astronaut and the orbiter although this may tangle around the arm during operation of the arm.

A further possibility would be to let the astronaut climb back along the arm. However, further investigation would be required to determine the effects on the thermal blanket and the EVA suit.

STRANDING

- POSSIBLE CAUSES

- BRAKE FAILURE
- POWER FAILURE
- MOTOR FAILURE

- POSSIBLE ACTIONS

- HAND RAIL ON ARM
- TETHER BETWEEN ASTRONAUT AND ORBITER



STABILIZER REQUIREMENTS

The stiffness of the SRMS arm in a straight arm configuration is 10 lb/in. Furthermore, the arm will back-drive if rated torque levels are exceeded. For MRWS OCP tasks performed at relatively high force levels, SRMS cannot react the resulting forces. The maximum force levels expected on the OCP can be estimated from anthropometric data. With feet anchored, the maximum push/pull forces that can be applied using one hand is approximately 50 lb; with two hands, 100 lb. The point of application of the force will be 5 ft from the stabilizer attach joint. The manipulator joints will be designed to provide an unloaded maximum tip speed of 1 ft/sec in the straight arm condition and an angular rate of 0.2 rads/sec. The stabilizer will be capable of applying in the straight arm condition a tip force of 75 lbf and a torque of 375 ft-lb and be able to withstand or react (with brakes ON) 150 lbf and 750 ft-lb, respectively. The stabilizer will have six joints in order to be able to grab on to the grapple fixture at any orientation and location within its reach envelope. A quick disconnect end effector interface will be provided to enable easy change-out of end effectors of different types.

The Development Test Article (DTA) stabilizer will be similar to the flight unit with the following exceptions. The shoulder yaw and pitch joints will have two motors each to enable the DTA stabilizer to lift 100 lb in addition to its own weight and withstand 100 lbf tip force.

STABILIZER REQUIREMENTS

- SRMS STIFFNESS 10 LB/INCH
- OPEN CHERRY PICKER MAXIMUM FORCE
 - FEET ANCHORED, ONE HAND PUSH/PULL, 50 LB
 - FEET ANCHORED, TWO HAND PUSH/PULL, 100 LB
- POINT OF APPLICATION 5 FT FROM ATTACH POINT
- STIFFNESS 100 LB/INCH
- UNLOADED MAXIMUM TIP SPEED 1 FT/SEC (STRAIGHT ARM)
- UNLOADED ANGULAR RATE 0.2 RADS/SEC
- ABILITY TO APPLY 75 LBF TIP FORCE (STRAIGHT ARM)
- ABILITY TO WITHSTAND 150 LBF TIP FORCE (STRAIGHT ARM)
- ABILITY TO APPLY 375 FT - LB TORQUE
- ABILITY TO WITHSTAND 750 FT - LB TORQUE
- NUMBER OF JOINTS - 6
- QUICK DISCONNECT END EFFECTOR

DTA REQUIREMENTS

- REQUIREMENTS SAME AS ABOVE WITH THE FOLLOWING EXCEPTIONS
 - ABILITY TO LIFT 100 LB (STRAIGHT ARM)
 - ABILITY TO WITHSTAND 100 LBF TIP FORCE (STRAIGHT ARM)



JOINT CHARACTERISTICS

To reduce the cost of the stabilizer, all joints will be identical. The DTA unit will have two motors at each of the shoulder joints. The required joint characteristics are shown on the table on the opposite page.

JOINT CHARACTERISTICS

| JOINT | SPEED RATIO | NO LOAD SPEED, RAD/SEC | MAX. TORQUE, FT-LB | BRAKE TORQUE, FT-LB | GEARBOX EFFICIENCY | TRAVEL LIMITS, DEG. |
|-----------|----------------|------------------------------|--------------------------|---------------------------|-----------------------|---------------------------|
| SH. YAW | 512 | 0.2 | 750 | 750 | 0.85 | $\pm 180^\circ$ |
| SH. PITCH | 512 | 0.2 | 750 | 750 | 0.85 | $\pm 120^\circ$ |
| EL. PITCH | 512 | 0.2 | 375 | 750 | 0.85 | $\pm 150^\circ$ |
| WR. PITCH | 512 | 0.2 | 375 | 750 | 0.85 | $\pm 120^\circ$ |
| WR. YAW | 512 | 0.2 | 375 | 750 | 0.85 | $\pm 120^\circ$ |
| WR. ROLL | 512 | 0.2 | 375 | 750 | 0.85 | CONT. |



DRIVE SYSTEM

The drive system in each of the joints will consist of three stages of 4:1 single planetary system at the output end to ensure low backlash and high drive system stiffness. For pivot type joints, a 8:1 bevel gear set will be used at the input end. This enables the location of the motor, brake, clutch and tachometer assembly in the arm segments and simplifies the packaging problem at the joint. Alternatively, the in-line joint configuration where the motor, tachometer, brake and clutch assembly is located in-line with the gearbox with a 8:1 two-pass spur gear system at input and can be used for all joints. A 1:4 two-pass spur gear system is used between the motor and the brake/clutch. The overall efficiency of the joint is estimated to be in excess of 85%. A through hole of 0.75 inch diameter is provided in the joints to act as wiring conduit.

DRIVE SYSTEM

- 3 STAGES OF 4:1 SIMPLE PLANETARY SYSTEMS AT OUTPUT END
- 8:1 BEVEL GEAR AT INPUT END IN PIVOT JOINTS
- 8:1 FROM 2 PASS SPUR GEARS AT INPUT END IN IN-LINE JOINTS
- 1:4 2 PASS SPUR GEAR SYSTEM BETWEEN MOTOR AND BRAKE/CLUTCH
- OVERALL EFFICIENCY IN EXCESS OF 85%
- OUTPUT STAGE
 - DIAMETRAL PITCH 20
 - MAXIMUM BENDING STRESS-35 000 psi
 - MAXIMUM CONTACT STRESS-145 500 psi



CONTROL SYSTEM

To enable evaluation of various control concepts, the DTA system will have provision for:

- Single joint drive
- Azimuth, elevation, reach, wrist pitch, wrist yaw and wrist roll drive (AER drive)
- Resolved rate control.

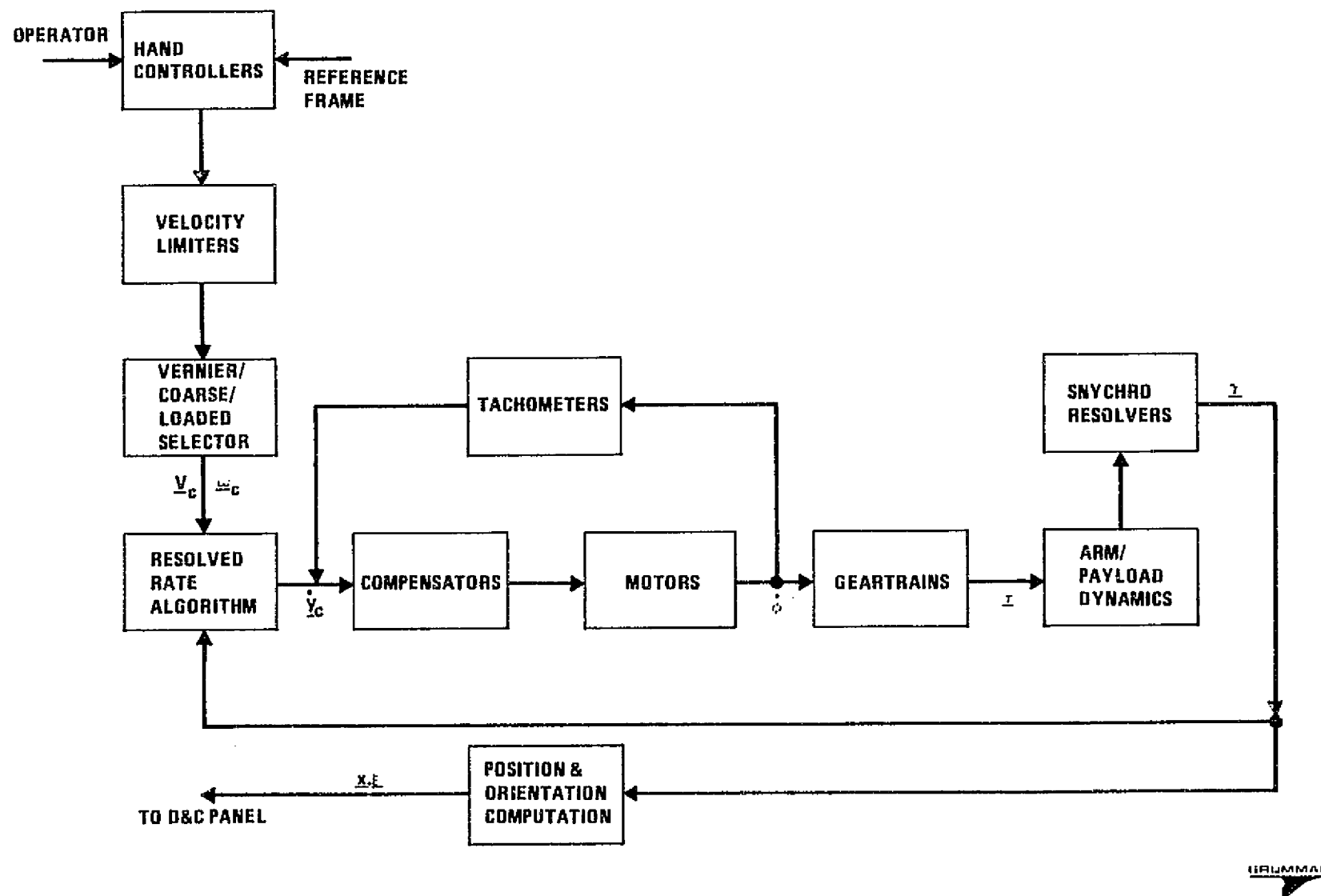
To meet the above requirement, the brakes and clutches in the joints can be controlled on a joint by joint basis or collectively.

The single joint drive and AER drive do not require position sensors. The AER drive can be implemented with a single hand controller (see opposite page).

RESOLVED RATE CONTROL

The facing page shows a simplified block diagram of the resolved rate control system. Synchro resolvers are used as position sensors. The velocity limiters, Vernier/course selector, resolved rate algorithm and position/orientation computation are software implemented.

RESOLVED RATE CONTROL – SIMPLIFIED BLOCK DIAGRAM



MOUNTING CONFIGURATION

There are three (3) possible mounting configurations for the stabilizer. These are:

- (a) Shoulder yaw axis forward
- (b) Shoulder yaw axis down
- (c) Shoulder yaw axis to side.

In case (a) resolved rate control singularity exists in the working region. The main advantage is, since the arm plane can be rotated around shoulder yaw axis, reaching around obstacles is easy. In cases (b) and (c) the resolved rate control singularity is outside the working region but there will be reach around problems.

MOUNTING CONFIGURATION

- **SHOULDER YAW AXIS FORWARD**
 - SINGLE JOINT DRIVE
 - AER DRIVE
 - RESOLVED RATE CONTROL SINGULARITY: NO LATERAL MOTION POSSIBLE IN THE VICINITY OF SHOULDER YAW AXIS
 - ARM PLANE CAN BE ROTATED AROUND SHOULDER YAW AXIS TO REACH AROUND OBSTACLES
- **SHOULDER YAW AXIS DOWN**
 - SINGLE JOINT DRIVE
 - AER DRIVE
 - RESOLVED RATE CONTROL: SINGULARITY REGION OUTSIDE WORKING REGION
 - REACH AROUND PROBLEMS
- **SHOULDER YAW AXIS TO SIDE**
 - SINGLE JOINT DRIVE
 - AER DRIVE: POOR CORRESPONDENCE
 - RESOLVED RATE CONTROL: SINGULARITY REGION OUTSIDE WORKING REGION
 - REACH AROUND PROBLEMS



FAILURE MODES

Possible failure modes of the stabilizer and the required actions are identified in the opposite page.

FAILURE MODES



FAILURE

- 1) BRAKE SEIZURE
- 2) CLUTCH SEIZURE
- 3) MOTOR FAILURE
- 4) TACH OR RATE LOOP FAILURE
- 5) END EFFECTOR MOTOR FAILURE
- 6) END EFFECTOR CLUTCH FAILURE
- 7) BRAKE & CLUTCH SEIZURE

ACTION

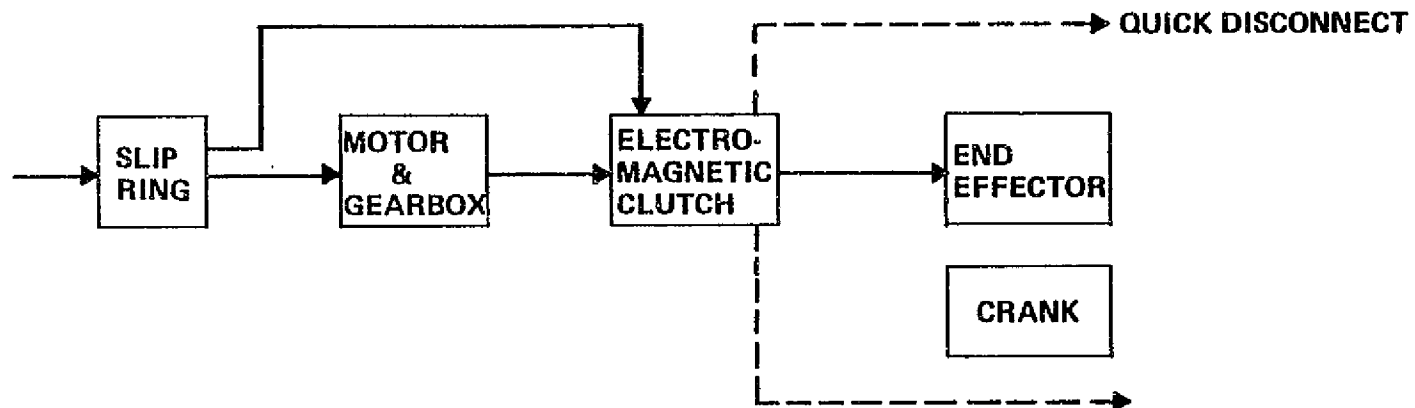
- 1) DISENGAGE CLUTCH AND DRIVE MOTOR
- 2) RELEASE BRAKE AND DRIVE MOTOR
- 3) RELEASE BRAKE OR DISENGAGE CLUTCH AND BACKDRIVE ARM
- 4) DIRECT DRIVE OF MOTOR
- 5) USE CRANK
- 6) USE CRANK
- 7) JETTISON STABILIZER



END EFFECTOR DRIVE

A schematic of the end effector drives system is shown on the opposite page. The quick disconnect feature enables the in-flight change-out of end effectors. By varying the voltage applied to the clutch, the grip force level can be varied. The crank permits release in the event of failures in the end effector drive system. Alternatively, a spring release mechanism can be provided to perform the same function.

END EFFECTOR DRIVE



- **TYPES OF END EFFECTORS:**
 - PARALLEL JAW
 - INTERNAL PICKUP TYPE
 - EXTERNAL PICKUP TYPE
 - OTHER
- **QUICK DISCONNECT ENABLES IN-FLIGHT CHANGING OF END EFFECTORS**
- **VARYING THE VOLTAGE APPLIED TO THE CLUTCH ENABLES THE CONTROL OF FORCE LEVEL**
- **CRANK PERMITS HANDLING OF FAILURES**

POWER ESTIMATE

The table on the opposite page shows the estimated power requirements for the stabilizer.

POWER ESTIMATE

| <u>JOINT</u> | <u>WATTS</u> |
|--------------|--------------|
| • MOTOR | 153 |
| • BRAKE | 8 |
| • CLUTCH | 8 |
| • SYNCHRO | <u>2</u> |
| TOTAL | 171 |

SHOULDER PITCH AND YAW JOINTS REQUIRE AN
ADDITIONAL 153 WATTS EACH

| <u>TOTAL POWER REQUIREMENTS</u> | <u>WATTS</u> |
|---------------------------------|--------------|
| • JOINTS | 1332 |
| • END EFFECTOR | 150 |
| • ELECTRONICS | <u>200</u> |
| TOTAL | 1682 |



WEIGHT ESTIMATE

The weight estimate for the stabilizer is shown in the table opposite. Further reduction in weight is possible by using lightweight materials.

WEIGHT ESTIMATE*

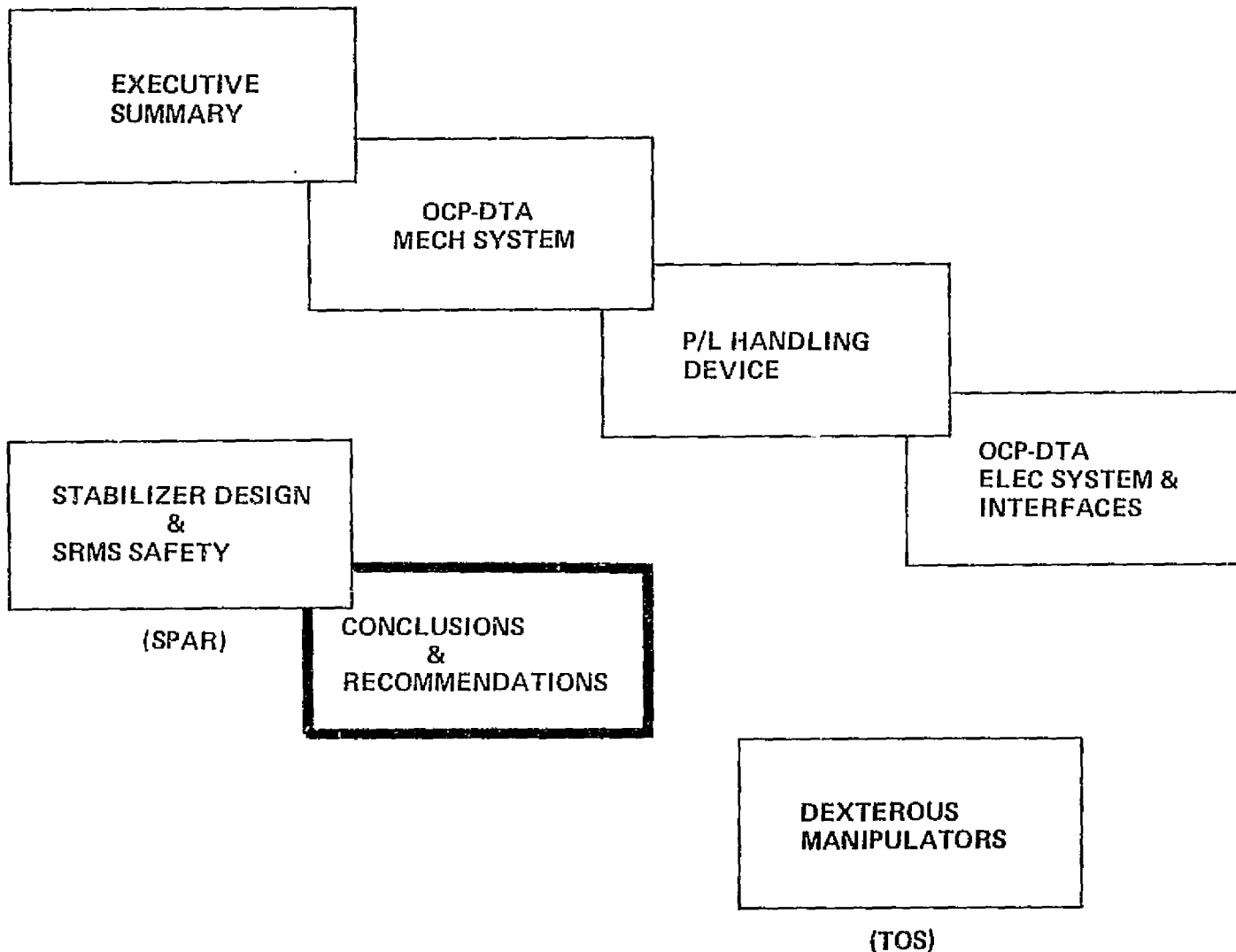
| <u>JOINT</u> | <u>LB</u> |
|-----------------|------------|
| MOTOR | 0.88 |
| TACH | 0.24 |
| CLUTCH | 0.68 |
| BRAKE | 0.56 |
| SYNCHRO | 0.5 |
| BEARINGS & MISC | 0.64 |
| GEARBOX | <u>8.0</u> |
| TOTAL | 11.5 |

SHOULDER PITCH AND YAW JOINTS REQUIRE AN
ADDITIONAL 0.88 LBS EACH

| <u>TOTAL WEIGHT</u> | <u>LB</u> |
|---------------------|-----------|
| JOINTS | 71 |
| ARM STRUCTURE | 35 |
| WIRING | 3 |
| MISC | 2 |
| END EFFECTOR | <u>9</u> |
| TOTAL | 120 |

*ASSUMING 1/8-INCH THICK,
5" DIA STEEL TUBING

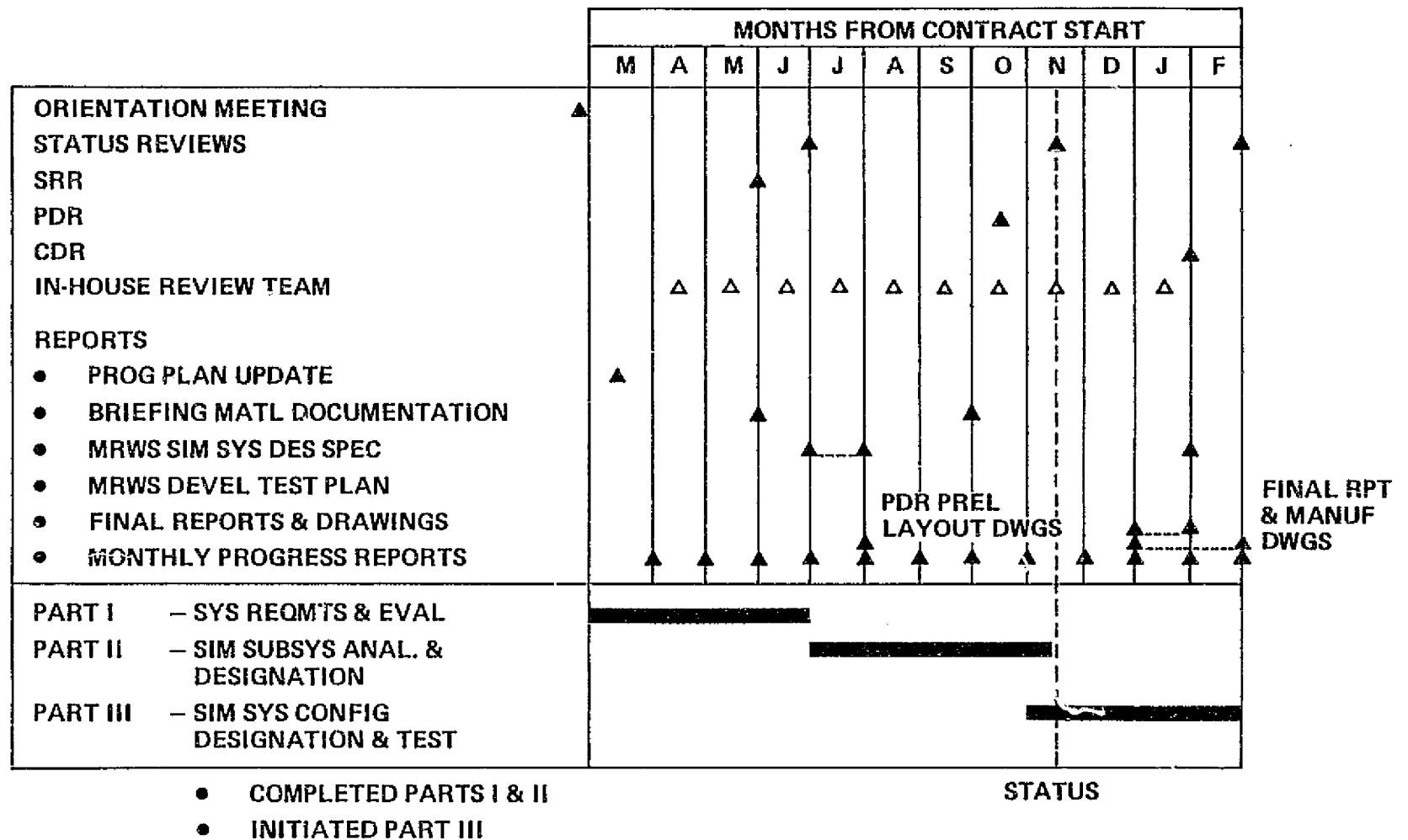




CONTRACT STATUS

The contract effort is now at the two-third point. Part I activity, which concentrated on flight article roles and missions, and identification of simulation requirements, was completed in June. The Part II activity is now complete, with the Preliminary Design Review (PDR) held in the middle of October. Part III activities will now be initiated with efforts concentrating on the preparation of engineering drawing, manufacturing plans and test plans for the open cherry picker development article.

CONTRACT STATUS



CONTRACT PLANS

Plans for the final part of the contracted effort is summarized on the facing page and delineated in subsequent discussion. The open Review Item Dispositions (RIDs) resulting from the PDR will be closed out by the end of Part III. The majority of RIDs will be closed out by the end of November by a Specification update and the remaining RIDs will be closed out with delivery of the engineering drawings. An expanded study effort of OCP applications in support of Satellite and Spacelab missions will be initiated as well as an expanded effort to define the plans and scheduling of the flight article. This expanded or emphasis test will be performed in parallel with the planned Part III activity.

CONTRACT PLANS

- CLOSEOUT PDR RIDS
- INITIATE PART III OF CONTRACT
 - PREPARE ENGINEERING DESIGN DRAWINGS
 - DEVELOP MANUFACTURING REQMTS/COST/SCHEDULE
 - PREPARE DTA DEVEL TEST PLAN
 - DEVELOP DTA PROCEDURES
- INITIATE EXPANDED STUDY EFFORT IN FOLLOWING AREAS:
 - OCP UTILIZATION IN SATELLITE SERVICES
 - OCP FLIGHT ARTICLE PROGRAM PLAN



PRELIMINARY DESIGN REVIEW (PDR) RESULTS

Fifty Review Item Dispositions (RIDs) were identified and discussed at the PDR. Of the fifty, 42 were identified in the Electrical/System working group and eight were discussed in the Structural-Mechanical group. The majority of the Electrical/System RIDs covered comments on the performance spec and should be closed out with an update of the documentation. Of the eight RIDs discussed in the Structural Mechanical group, five were closed and the three remaining RIDs should be covered with an update of the manufacturing drawings.

The major outstanding RIDs are listed on the facing page. Most of these RIDs involve man-machine interfaces that cannot be fully answered until simulation is performed. The resulting design impact of these dispositions is to provide as much flexibility in the test article to evaluate a full range of possibilities.

The following charts delineate each of the five key items.

CONTROLS/DISPLAY CONSOLE ARRANGEMENT (CONTD)

| | | |
|--------------------------------------|---|---|
| <p>4) REMOTE MANIPULATOR CONTROL</p> | <p>4-1 (7) SEVEN BUTTON PUSH-BUTTON SWITCH/LIGHT ASSEMBLY 4-2 (3) THREE POSITION MOMENTARY SWITCH 4-3 (3) THREE POSITION SWITCH 4-4 (2) TWO POSITION SWITCH 4-5 (2) TWO POSITION SWITCH 4-6 ANNUNCIATOR LIGHT 4-7 ANNUNCIATOR LIGHT</p> | <p>TO SELECT INDIVIDUAL RMS JOINTS TO BE DRIVEN IN THE SINGLE JOINT DRIVE MODE, ONLY ONE PUSHBUTTON CAN BE DEPRESSED AT A TIME</p> <p>PERMITS OPERATOR TO DRIVE INDIVIDUAL RMS JOINTS SELECTED IN A CW, CCW DIRECTION, CENTER POSITION OFF</p> <p>SELECTS POWER TO EITHER PORT OR STARBOARD RMS</p> <p>SELECTS RMS POWER ON/OFF ENABLES OPERATOR TO APPLY OR RELEASE SIMULTANEOUSLY THE BRAKES TO ALL RMS JOINTS INDICATES ALL RMS BRAKES ON/OFF INDICATES POWER ON/OFF</p> |
| <p>5) FUNCTION CONTROL</p> | <p>5-1 (4) FOUR BUTTON PUSH-BUTTON SWITCH/LIGHT ASSEMBLY</p> | <p>PROVIDES FOR SELECTION OF TWO MODES OF CONTROL FOR BOTH THE MDF-RMS AND THE DTA STABILIZER (a) MANUAL AUGMENTED (b) DIRECT DRIVE. ONLY ONE PUSHBUTTON CAN BE DEPRESSED AT A TIME</p> |
| <p>6) CAUTION & WARNING</p> | <p>6-1 (8) EIGHT ANNUNCIATOR LIGHTS</p> <p>6-2 TWO-POSITION MAINTAIN PUSHBUTTON SWITCH/LIGHT</p> | <p>CAUTION SINGULAR – INDICATES THAT THE CONFIGURATION OF THE MANIPULATOR ARM IS APPROACHING AN ARM SINGULARITY CONDITION.</p> <p>CAUTION CONTR ERR – INDICATES CERTAIN JOINT ABNORMAL CONDITIONS WHICH MAY NOT BE DETECTED BY BITE.</p> <p>CAUTION REACH LIM – INDICATES THAT THE MANIPULATOR ARM HAS REACHED A CONFIGURATION THAT ONE OF THE JOINTS IS CLOSE TO ITS REACH LIMIT</p> <p>WARNING MCIU – INDICATES THAT A FAILURE HAS OCCURRED IN THE MCIU</p> <p>WARNING ABE – INDICATES THAT A FAILURE HAS OCCURRED IN THE ARM BASED ELECTRONICS (ABE)</p> <p>WARNING GPC DATA – INDICATES THAT INVALID DATA HAS BEEN TRANSMITTED BY THE ORBITER GPC TO THE SRMS MCIU. THIS WARNING SIGNIFIES EITHER A GPC OR GPC TO MCIU DATA COMMUNICATIONS FAILURE AS DETECTED BY MCIU BITE PROVISIONS. THIS WARNING IS ACCOMPANIED BY THE SIMULTANEOUS EXECUTION OF THE SRMS SAFING ROUTINE</p> <p>WARNING DERIGIDIZE – INDICATES THAT THE END EFFECTOR TO PAYLOAD GRAPPLE POINT INTERFACE HAS DERIGIDIZED WITHOUT HAVING BEEN COMMANDED TO DO SO BY THE OPERATOR</p> <p>WARNING RELEASE – INDICATES THAT THE END EFFECTOR HAS RELEASED THE PAYLOAD GRAPPLE POINT WITHOUT HAVING BEEN COMMANDED TO DO SO BY THE OPERATOR</p> <p>PUTS COMPUTER IN A FREEZE MODE</p> |

PRELIMINARY DESIGN REVIEW (PDR) RESULTS

REVIEW ITEM DISPOSITIONS

| | <u>NO. SUBMITTED</u> | <u>NO. CLOSED</u> |
|----------------------|----------------------|-------------------|
| • ELECTRICAL/SYSTEMS | 42 | 26 |
| • STRUCTURAL MECH | 8 | 5 |

KEY ITEMS

- C&D PANEL LAYOUT & COMPONENTS
- C&D PANEL HEIGHT VARIATIONS
- SELF-LOCKING MECHANISMS
- LIGHT ADJUSTMENT
- WAIST RESTRAINT

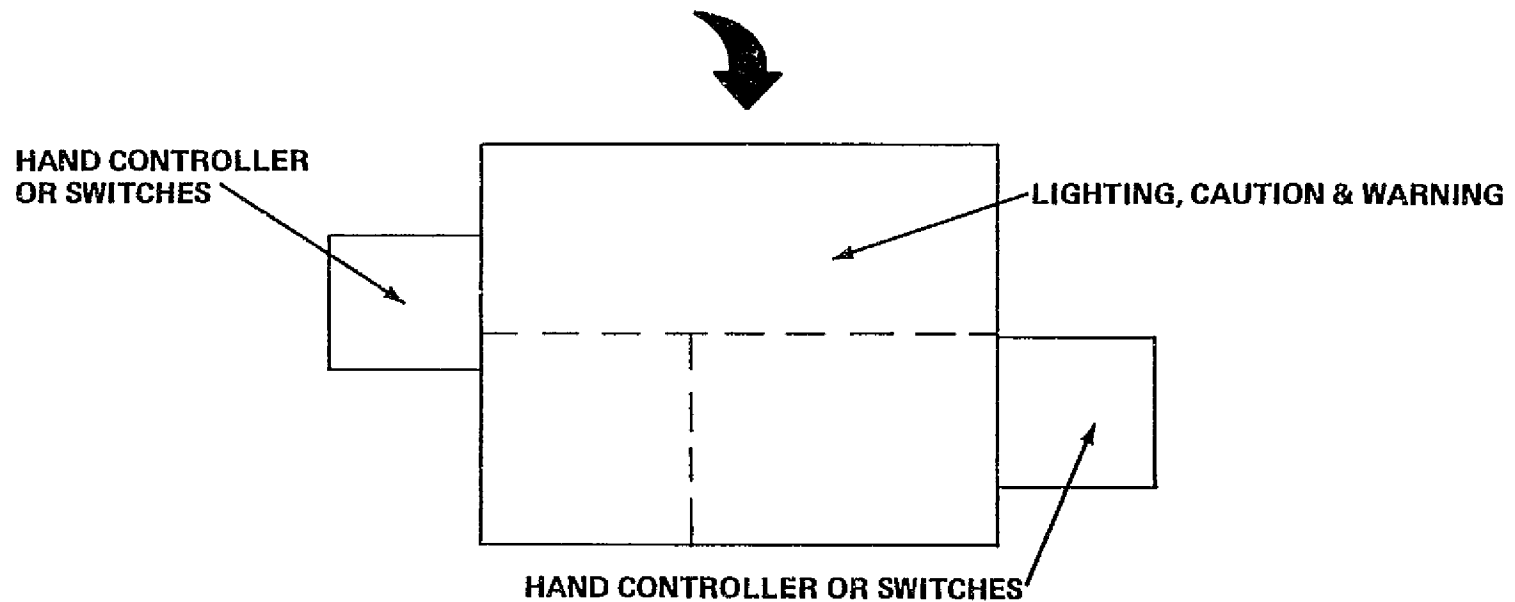


D&C PANEL LAYOUT AND COMPONENTS GUIDELINES

The facing page summarizes the guidelines established at the PDR for the D&C panel. It was decided not to be constrained by the availability of Shuttle D&C components, but rather to leave selection of switches, indicators and controllers subject to the results of simulation. The objective is to use the Development Test Article as a technology tool for advancing D&C technology. The constraint to use standard 19 in. panels was also dropped giving precedence to requirements for compact storage volume. It was also decided to strive for a modular layout of D&C functions so that parts of the D&C panel can be changed during simulation.

D&C PANEL LAYOUT & COMPONENTS GUIDELINES

- DO NOT ASSUME WE MUST USE SHUTTLE COMPONENTS ---
DTA IS FOR DEVELOPING NEW TECHNOLOGIES
- STANDARD 19 INCH PANEL SPEC DOES NOT HAVE TO BE ADHERED TO
- DESIGN A MODULAR APPROACH TO PANEL LAYOUT BY GROUPING LIKE
FUNCTIONS FOR READING CHANGEOUT OF COMPONENT APPROACHES

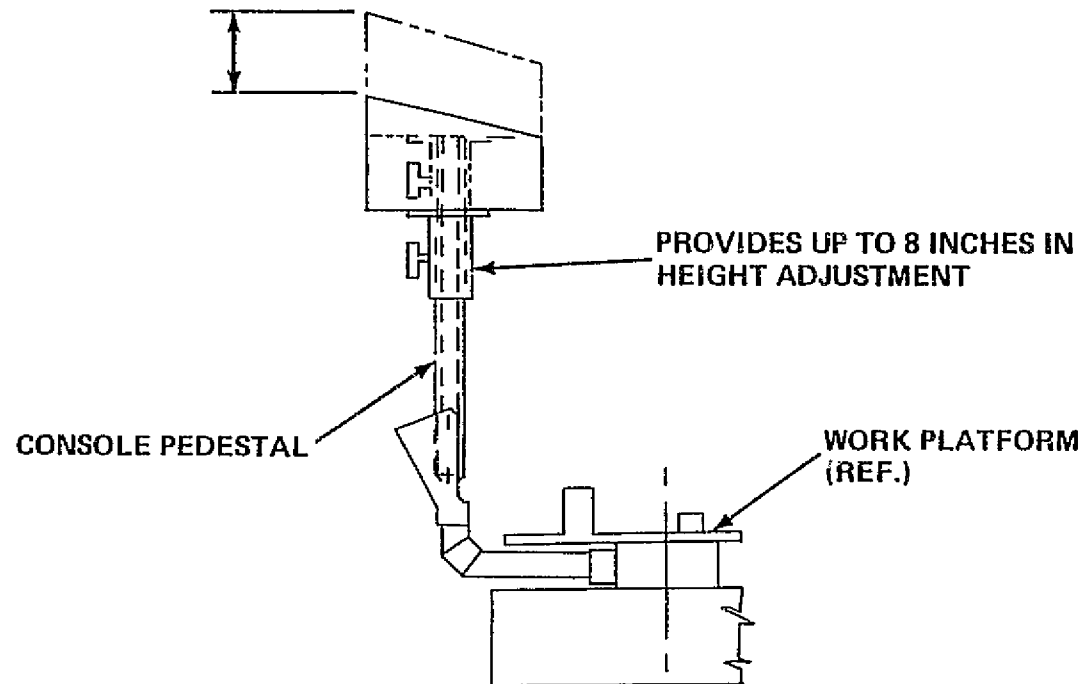


D&C PANEL HEIGHT ADJUSTMENT

The DTA design presented at the PDR featured a fixed height for the D&C panel, providing flexibility for the range of heights of the operators with an adjustable rotation of the hand controllers. Though this arrangement provides ready reach of the controllers for the range of operators (5% women to 95% men) visibility of the panel by taller men was thought not to be adequate. It was decided that a mechanism be added to the D&C panel support post for height adjustment and that selection of the proper height be an output of simulation.

D&C PANEL HEIGHT ADJUSTMENT

- UNCERTAINTY IN REQD PANEL HEIGHT
MAKE IT DESIRABLE TO HAVE HEIGHT
ADJUSTMENT ON DTA PANEL



2700-171W

SELF-LOCKING MECHANISM

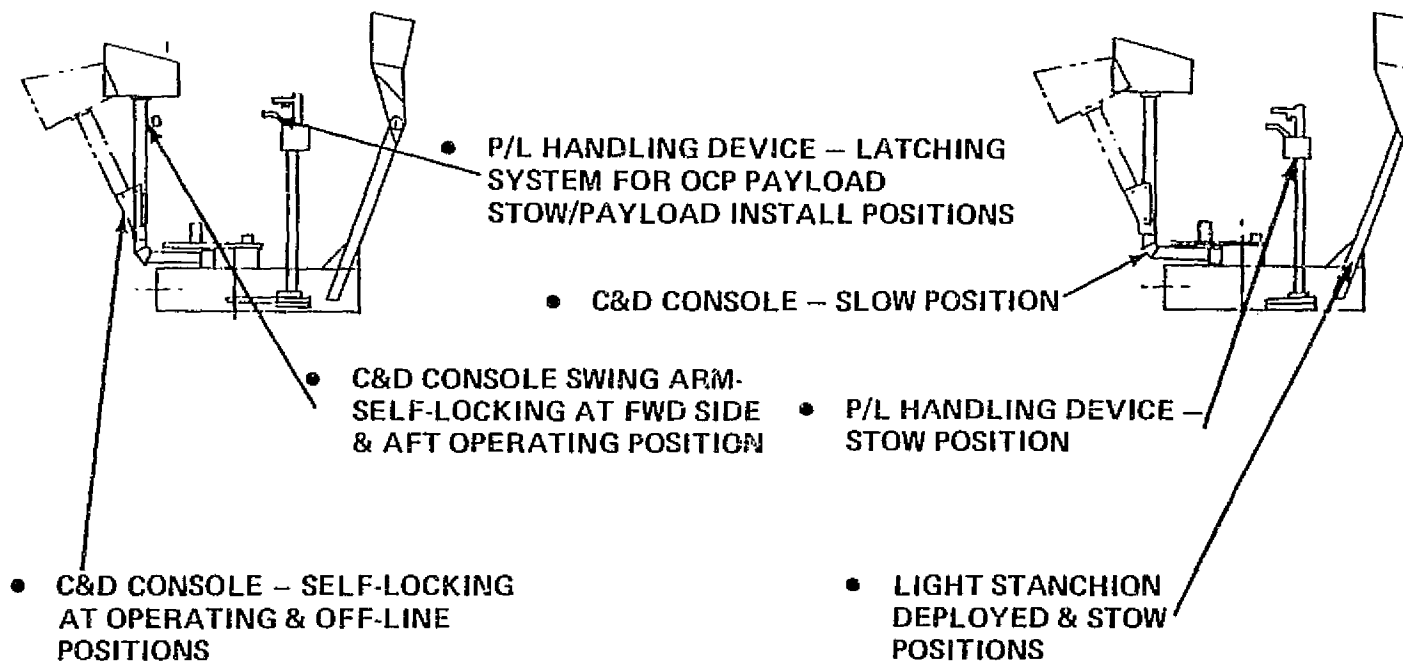
The agreements reached on mechanical locking systems are summarized on the facing page. Those mechanisms used in the operation of the system for satellite servicing, construction, etc. are to be automated while those mechanisms associated with folding and unfolding the OCP-DTA can be manual. Those mechanisms for the fold-unfold operations will be automated for the flight article.

Self-locking mechanisms are required for operating the D&C panel swing arms, positioning the D&C panel off-line, operating the foot restraint rotary bearing, and operating the P/L handling device swing arms. Self-locking mechanisms are not required for stowage of the D&C panel, light stanchion and P/L handling device.

SELF-LOCKING MECHANISM

SELF-LOCKING MECHANICAL
SYSTEMS REQD ON DTA

SELF-LOCKING SYSTEMS
NOT REQD



NOTE: SELF-LOCKING MECHANISMS REQUIRED; WILL BE COMPATIBLE WITH EMU SUITED OPERATOR WORKING FROM FOOT RESTRAINT PLATFORM.

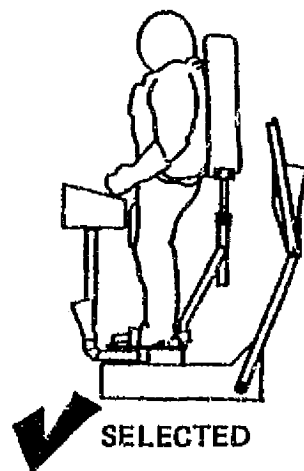
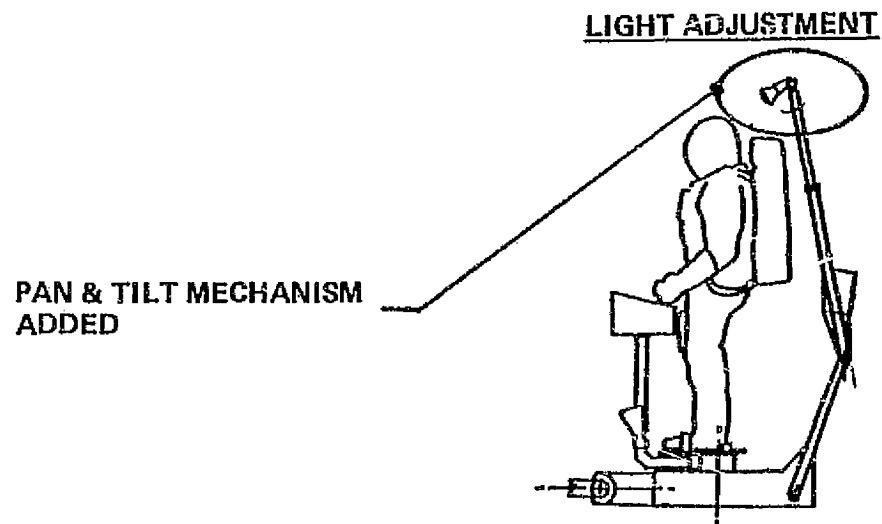
GRUMMAN

KEY ISSUES (CONTINUED)

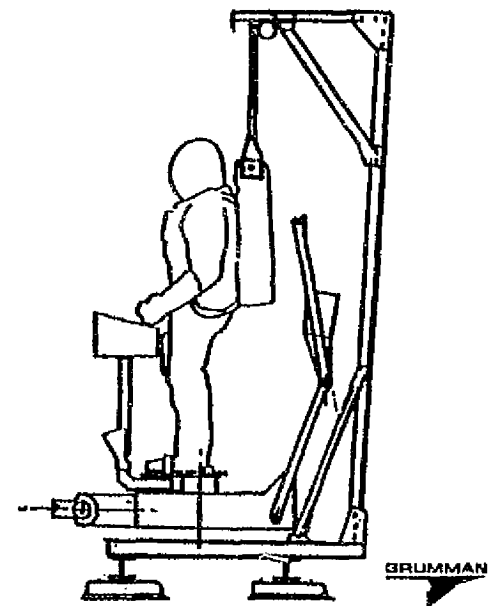
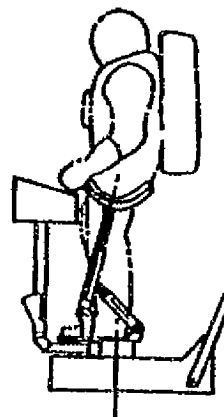
A pan and tilt mechanism was added to the light stanchion to allow manual adjustment. This mechanism will be located at the top of the stanchion. Options to this location will be investigated.

Three options for a simulator safety/rest restraint system were considered. The three, presented on the facing page, include a simple support bar to the EMU back-back, a bicycle seat and a peter-pan rig. The simple bar support was selected because it meets requirements with minimum impact on operations of the system.

KEYS ISSUES (CONTINUED)



SAFETY/REST RESTRAINT



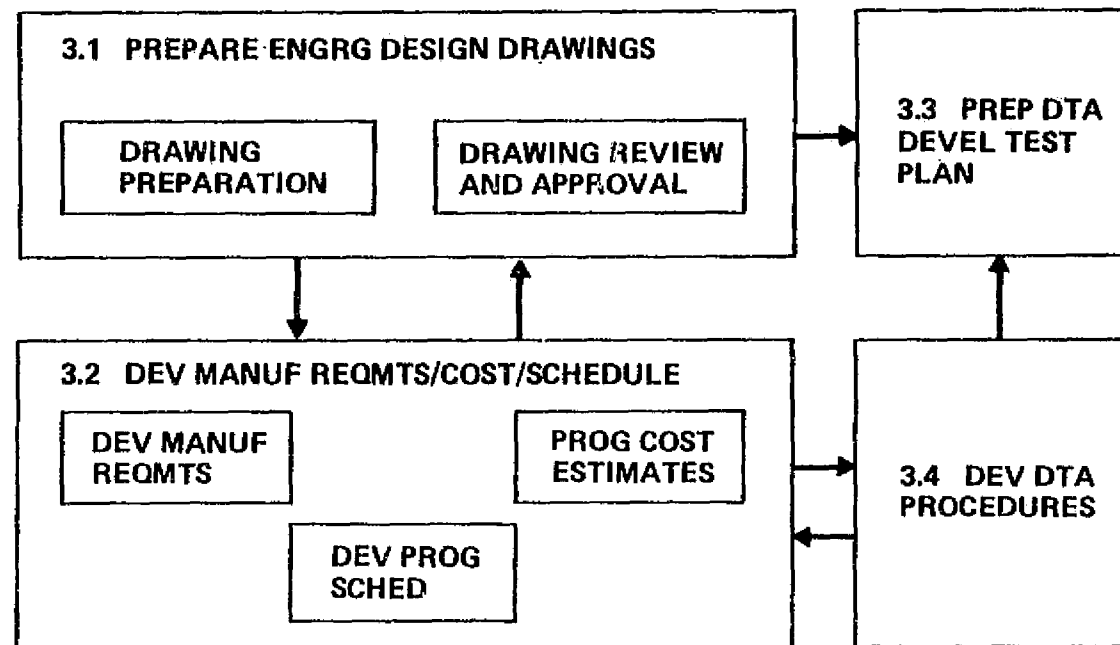
PART III - SIMULATED SYSTEM CONFIGURATION DESIGN AND TEST - TASK FLOW

A summary of the task flow for Part III of the contract effort is shown. Simulator System Configuration and Test is broken into the following four tasks:

- Preparation of Engineering Design Drawings
- Development of Manufacturing Requirements/Cost/Schedule
- Preparation of DTA Development Test Plan
- Development of DTA Procedure

The objective of Task 3.1 is to generate the structural, mechanical and electrical design drawings to manufacture the DTA. Task 3.2 will utilize the engineering drawings to establish manufacturing requirements including schedule and cost, while Task 3.3 will key off the test requirements developed in Part I and II of the study and schedule them into a test sequence. Task 3.4 will provide DTA installation, servicing, checkout and operations procedures.

PART III – SIMULATOR SYSTEM CONFIGURATION DESIGN AND TEST – TASK FLOW



INPUTS

PART I

- DES SPEC
- SIM REQMTS

PART II

- CONFIG LAYOUT
- DES PERF SPECS
- ALLOCATED TEST REQMTS

OUTPUTS

- FINAL REPORT
- MANUF DWGS
- INTERFACE DWGS
- MANUF REQMTS DCC., COST & SCHEDULES
- DEVEL TEST PLAN
- OPERATING PROCEDURES



CANDIDATE SATELLITES AND SPACELAB MISSIONS FOR OCP SERVICES

A preliminary list of satellites and spacelab experiment categories that will be evaluated for servicing by an EVA crew operating from the open cherry picker is shown. Emphasis will be placed on identifying the least replaceable unit that could be handled by an EVA/OCP system along with identification of potential tools and procedures that are used to perform the servicing function.

CANDIDATE SATELLITES & SPACE LAB MISSIONS FOR OCP SERVICES

SATELLITES

- SPACE TELESCOPE
- 1.2 m X-R OBSERVATORY
- GAMMA RAY OBSERVATORY
- SOLAR MAX
- LDEF
- LANDSAT
- SPACE TECHNOLOGY RESEARCH SAT.
- 25 kW POWER MODULE
- TIROS
- GOVT EARTH RESOURCES
- SEAT
- INRESAT

SPACE LAB. PALLETS (GENERIC)

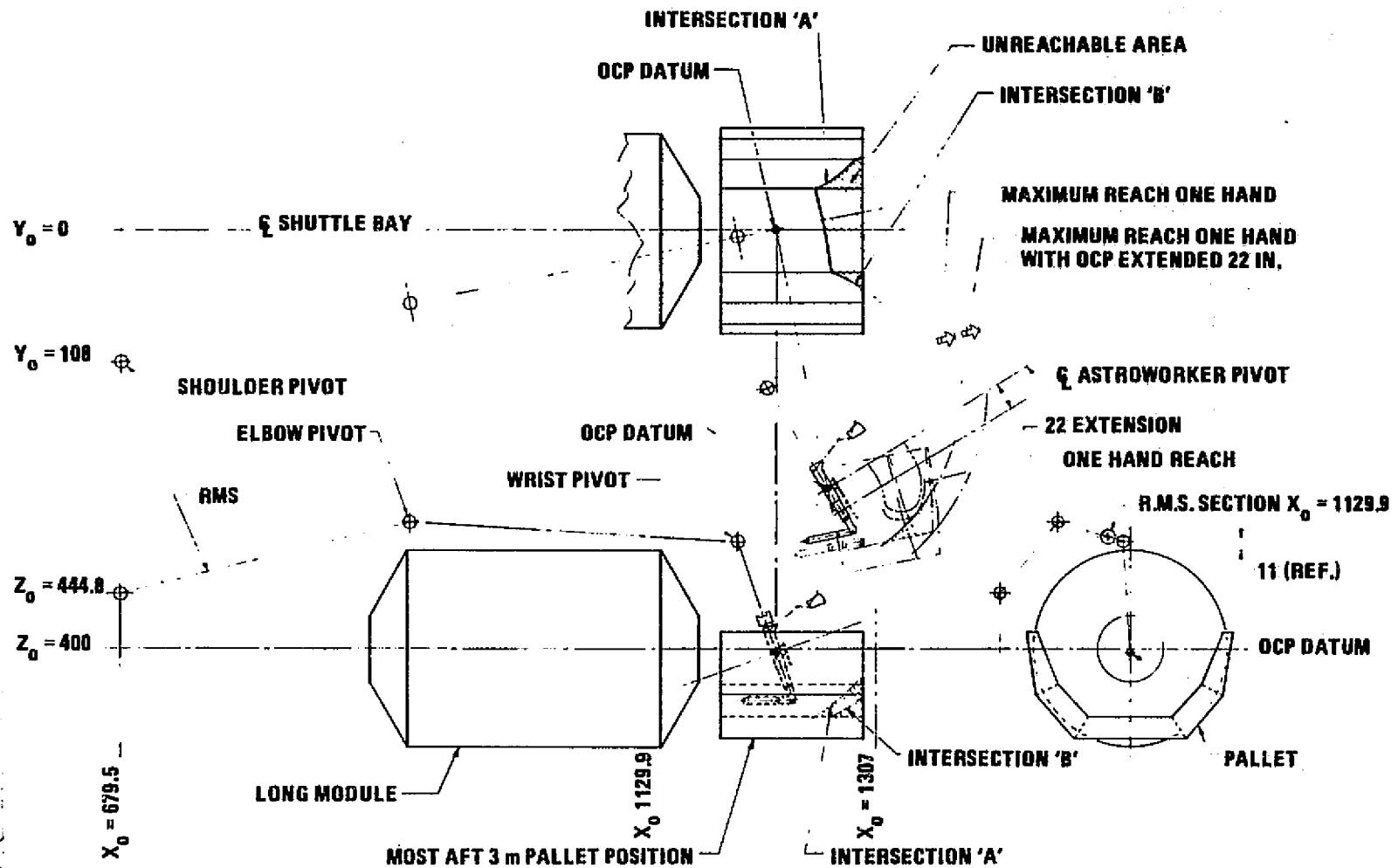
- SPACE TECHNOLOGY
- PI CLASS PAYLOADS
- STARLAB
- SIRTf
- MULTI-INSTRUMENT PACKAGES
- SPACE PROCESSING/MANUFACTURING
- COMMUNICATIONS
- GLOBAL RESOURCES
- PHYSICS & ASTRONOMY
- SOLAR PHYSICS



OCP/RMS REACH ENVELOP WITH SPACELAB

One key issue that relates to servicing spacelab pallet experiments is the potential interference a spacelab module will impose on OCP/RMS reach. The facing page presents a reach envelop for the case in which a long spacelab module is placed in front of a single pallet. With proper programming of the shoulder, elbow and wrist location, it is feasible for an open cherry picker astronaut to reach and service equipment located on the rear mounted pallet.

OCP/RMS REACH ENVELOP WITH SPACELAB



MRWS OPEN CHERRY PICKER PROGRAM PLAN

The facing page summarizes the objectives and a candidate approach for formulating the OCP flight vehicle program plan. The objective is to keep program costs low by utilizing as much functional and hardware elements of the development test article in the qualification of the flight article, as well as, ultimately utilizing the DTA as the ground based trainer for the flight program.

The approach would utilize the DTA designed for 1 g operation at the Manipulator Development Facility as a tool for qualifying man-machine interfaces and certain self-locking mechanisms. This DTA would then be updated to a high fidelity simulator of the flight article and used as a trainer. A mockup should also be introduced into the inventory, namely: a lightweight model that is a mockup of the folded configuration. This model should be used at the MDF to simulate RMS grappling procedures and the stow/unstow features of the OCP to Shuttle interface hardware.

A second DTA (DTA-2) is needed for WIF testing, and a third (DTA-3) as a structural test article.

The flight article itself would be used as the qual-unit for functional, EMC and thermal/vacuum testing. It would be refurbished after testing and used for flight.

MRWS OPEN CHERRY PICKER PROGRAM PLAN

OBJECTIVE

- UTILIZE DEVELOPMENT TEST ARTICLES AS INTEGRAL PART OF FLIGHT ARTICLE QUAL PROGRAM
 - SELECTED STRUCTURAL/MECHANICAL SYSTEM ELEMENTS
 - MAN/MACHINE INTERFACES
 - SHUTTLE INTERFACES
- UTILIZE DEVELOPMENT TEST ARTICLES AS TRAINERS

APPROACH

- THREE DTAs & FLT ARTICLE REQUIRED
 - DTA 1: DESIGNED TO 1g FOR SIMULATION;
UPDATE FOR USE AS TRAINER
 - DTA 2: DESIGN AS WIF MODEL; UPDATE AS TRAINER
 - DTA 3: DESIGNED FOR CONTRACTOR SIM; UPDATED TO A
STRUCTURAL TEST ARTICLE
 - LITE/WGT MODEL: FORM & FIT SIMULATOR TO TEST
RMS/SHUTTLE TIE-DOWN SYSTEMS &
OPS
 - FLT ARTICLE USED AS QUAL TEST UNIT AND REFURBED FOR FLT

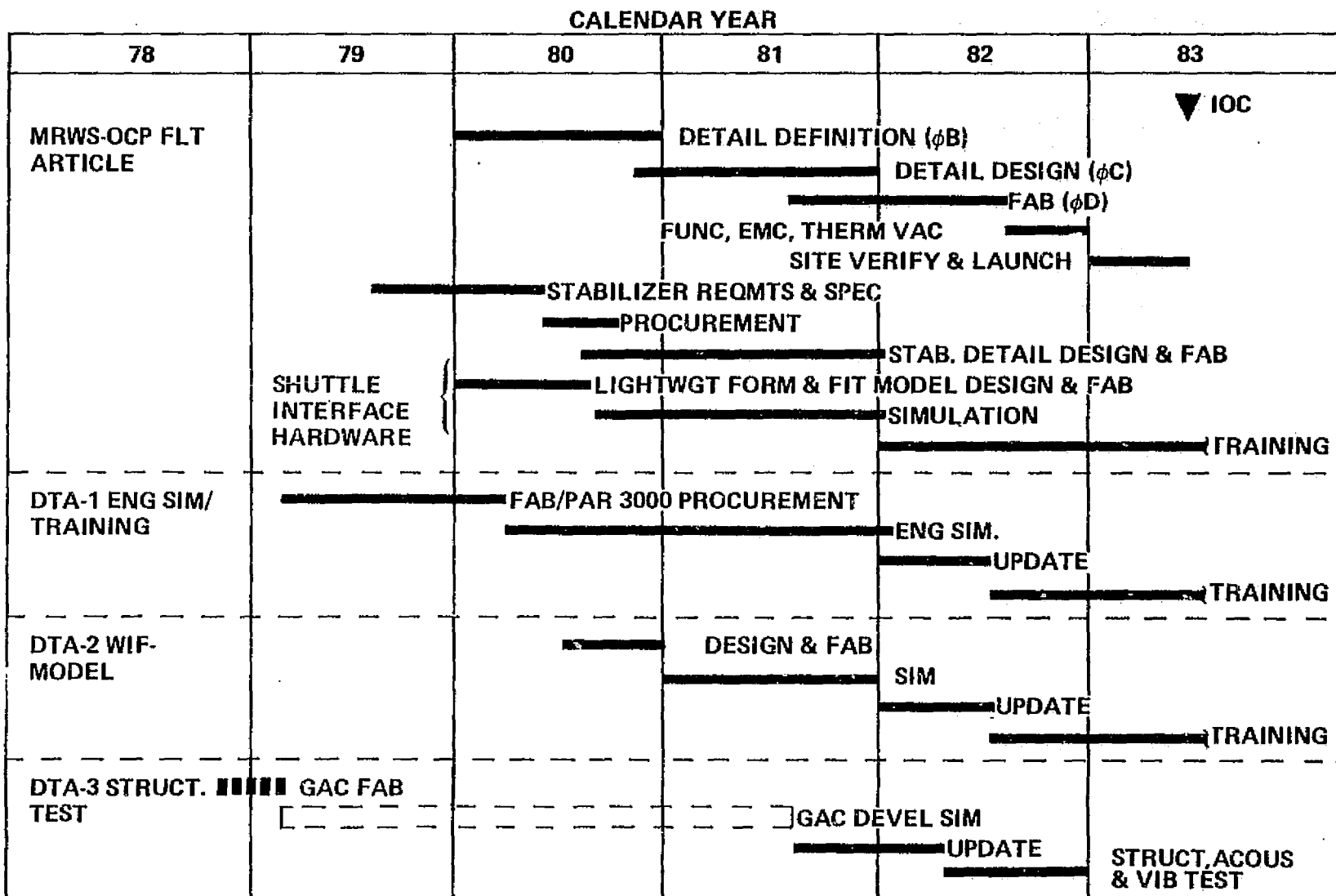


PRELIMINARY MRWS OPEN CHERRY PICKER PROGRAM SCHEDULE

The facing page presents a schedule for flight article development that utilized the three DTA's discussed previously. Engineering simulation is performed in parallel with Phase B and Phase C activities to provide design requirements. At the end of Phase C, DTA-1 is updated and used for training. Design and fabrication of DTA-2 is initiated in 1980 and used in WIF simulation and ultimately training. DTA-3 is used for structural tests and contractor related development simulation.

The schedule on the facing page is considered conservative. A IOC of mid 1982 could be achieved by shortening Phase B activities and the time allocated to qualification testing.

PRELIMINARY MRWS OPEN CHERRY PICKER PROGRAM SCHEDULE



GRUMMAN

RECOMMENDATIONS

Preliminary program plans for the open cherry picker flight article and the parallel plans for the Development Test Article, as well as the budgetary restrictions in 1979 and 1980 are the basic considerations in formulating the following recommendations:

- (1) Initiate DTA fabrication and procurement of a commercial stabilizer in 1979.
- (2) Utilize the OCP mockup, now at Grumman, in under water tank tests for man-machine interface evaluations in 1979.
- (3) Delay development of simulator software and MDF simulations until 1980.
- (4) Design and fabricate the lightweight DTA-2 in 1980.
- (5) Initiate Phase B in 1980 followed by a Phase C/D award in 1981.

RECOMMENDATIONS

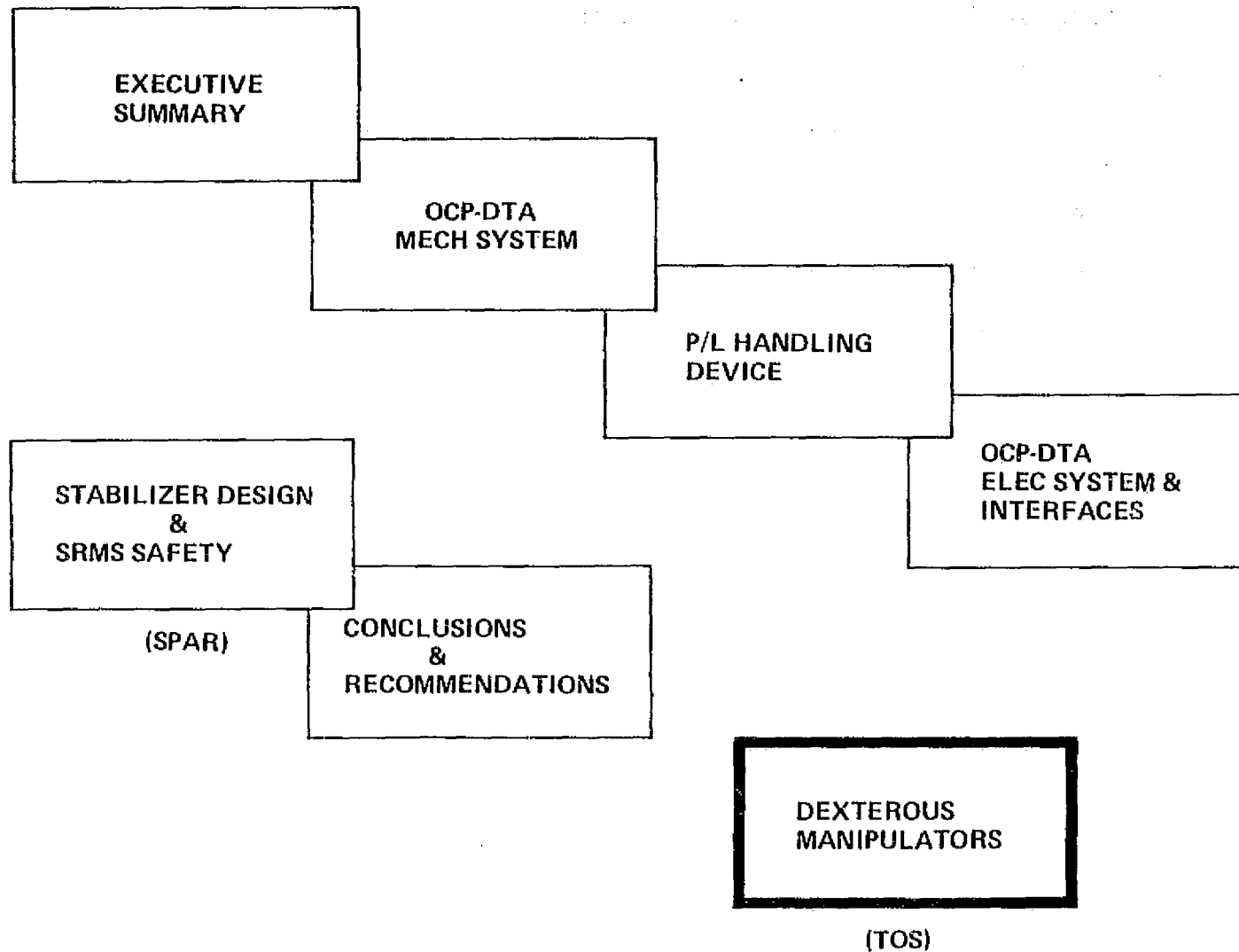
OCP THREE YEAR PLAN

| ELEMENT | 79 | 80 | 81 |
|-----------------------|----|----|----|
| FLIGHT ARTICLE | | | |
| • DETAIL DEF | | | |
| • DETAIL DESIGN | | | |
| • FAB & TEST | | | |
| • STAB. DESIGN & FAB | | | |
| DTA-1 | | | |
| • FAB & STAB PROC | | | |
| • SIM SOFTWARE | | | |
| • SIM SUPPORT | | | |
| DTA-2 | | | |
| • DESIGN & FAB | | | |
| • SIM | | | |

- INITIATE FABRICATION OF OCP AND STABILIZER PROCUREMENT IN 1979
- UTILIZE OCP MOCKUP IN WATER TANK MAN/MACHINE INTERFACE EVAL IN 1979
- DEVELOP SIMULATOR SOFTWARE & PERFORM SIMULATIONS IN 1980
- DESIGN & FAB LIGHTWEIGHT DTA-2 IN 1980
- INITIATE DESIGN DEFINITION OF FLIGHT ARTICLE IN 1980



PRECEDING 1



MRWS DEXTEROUS MANIPULATOR LABORATORY VERSION

The developmental article manipulator has the following tasks:

- Verify what type of control mode will yield the highest productivity
- Verify that the manipulator with this control mode can do all desired operations
- Collect design data on some crucial parameters for flight hardware design. These include:
 - Required motor duty cycle
 - Desired force reflection ratios for zero g
 - Maximum desired master force
 - Typical operation times for major tasks.

MRWS DEXTEROUS MANIPULATOR LABORATORY VERSION

- **CAPABLE OF BEING CONTROLLED IN THE FOLLOWING MODES:**
 - **BILATERAL FORCE REFLECTING (BFR)**
 - **REPLICA NON-FORCE REFLECTING (NFR)**
 - **RESOLVED MOTION RATE CONTROL (RMR)**
 - **ORDINARY RATE CONTROL**
- **DESIGN IS DRIVEN BY BFR MODE REQUIREMENTS**
- **BFR DESIGN CAN ACCOMMODATE ALL OTHER CONTROL MODES WITHOUT PERFORMANCE DETERIORATION**
- **DESIGNS BASED ON OTHER CONTROL MODES CANNOT ACCOMMODATE BFR MODE**

SLAVE MANIPULATOR CHARACTERISTICS LABORATORY VERSION

The laboratory version manipulator is a direct adaptation of the present state of the art. This results in:

- Low development risk
- Lower design and construction costs
- Better understanding of the critical simulation issues from the manipulator point of view

It is a fortuitous coincidence that major parameters for development and flight hardware coincide with the existing State-of-the-art equipment. These include:

- DC motor drive
- Counterbalance system allowing zero g simulation
- Tendon wrist motion drive allowing dynamic equivalency to flight hardware.

SLAVE MANIPULATOR CHARACTERISTICS

LABORATORY VERSION

- BASED ON EXISTING TECHNOLOGY: LOW RISK
- MECHANICAL COUNTERBALANCE: ZERO G SIMULATION
- MOTOR WEIGHT FOR COUNTERBALANCING: LOW OVERALL WEIGHT
- DC MOTOR DRIVES: COMPACT CONFIGURATION
- TENDON DRIVE OF WRIST MOTIONS: LOW INERTIA
- SEVEN DEGREES-OF-FREEDOM PLUS END EFFECTOR ALL CAPABLE OF BFR MODE
- OVERALL LENGTH - 2 m (80 IN.); CAN BE MODIFIED
- TIP FORCE 66.7 N (15 LB)
- NO LOAD SPEED; AT LEAST 30 IN./SEC



SLAVE MANIPULATOR DESIGN LABORATORY VERSION

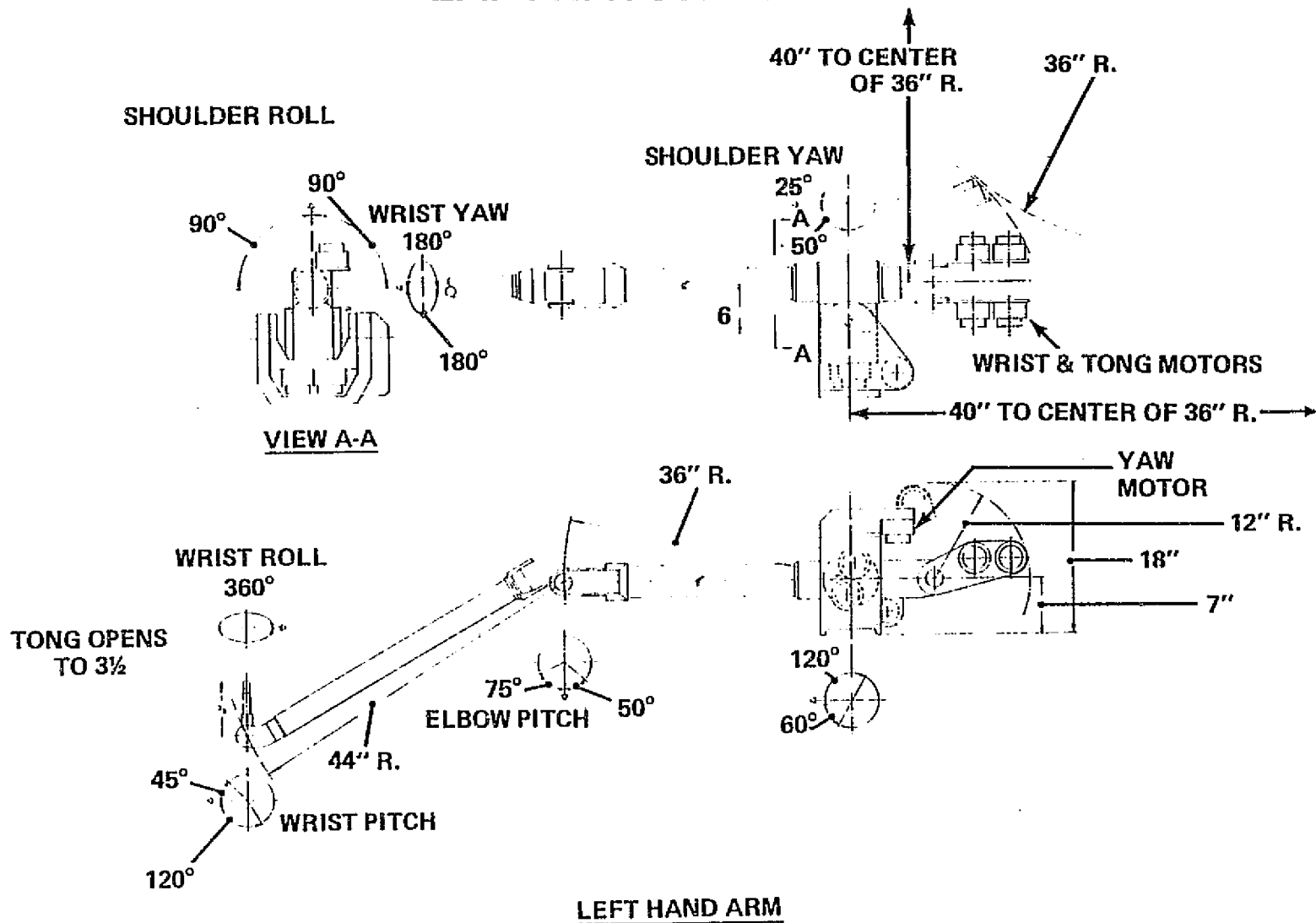
The laboratory manipulator has seven degrees of freedom plus an end effector drive. These are:

- Shoulder yaw
- Shoulder pitch
- Shoulder roll
- Elbow pitch
- Wrist yaw
- Wrist pitch
- Wrist roll
- End effector

This constitutes one more degree of freedom than normally used, the extra one is the shoulder yaw motion.

In most of the candidate control modes the shoulder yaw motion will be controlled in a different control mode than the rest of the manipulator. This is done to avoid kinematic or mathematical singularities of the seven degrees of freedom arm.

SLAVE MANIPULATOR DESIGN LABORATORY VERSION



GRUMMAN

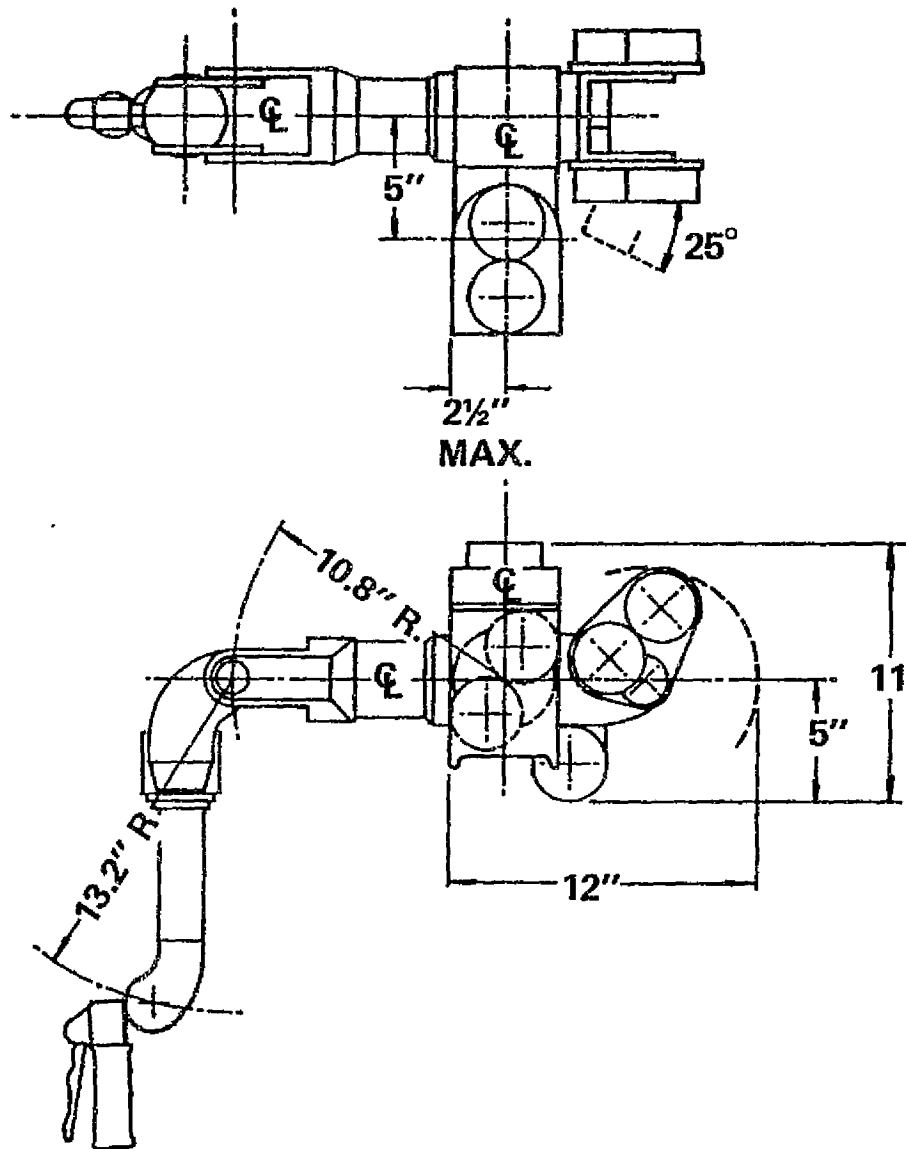
MASTER MANIPULATOR DESIGN LABORATORY VERSION

The master controller is a kinematic analogue of the laboratory manipulator, but 3.33 times smaller. It can be used to drive the laboratory manipulator in the following modes:

- BFR - Bilateral force reflecting
- NFR - No force reflecting replica
- RMR - Resolved motion rate with force reflection

It could possibly be adapted to simulate other control modes.

MASTER MANIPULATOR DESIGN — LABORATORY VERSION



GRUMMAN

MASTER CONTROLLER DESIGN FEATURES

While the master controller is primarily intended to control the laboratory manipulator in a 1:1 angular mode, it has enough velocity capability so that it can be used in a 1:1 linear mode (3.33:1 angular mode). The advantages of either one of these or intermediate modes are to be explored in simulation.

MASTER CONTROLLER DESIGN FEATURES

- BASED ON MANIPULATOR GEOMETRY (DOWN-SIZED REPLICA)
- DESIGNED FOR BFR CONTROL MODE
- CAPABLE OF NFR CONTROL MODE
- MAXIMUM VELOCITY CAPABILITY > 30 IN./SEC
- VARIABLE ANGULAR VELOCITY RATIO WITH RESPECT TO SLAVE: 1:1 TO 33:1
- TIP FORCE CAPABILITY 31.1 N (7 LB)
- LOW DISSIPATION MOTOR: 90 W PER ARM IN 1 G MODE
- FLIGHT VERSION DISSIPATION: 30 – 40 W PER ARM IN ZERO G MODE



DETAIL DESIGN FEATURES

As the driving control mode for manipulator design is BFR, the state of the art BFR design configurations should be utilized. The shoulder pitch and roll drive is an example.

A differential drive is utilized to achieve lower overall gear ratios thereby achieving:

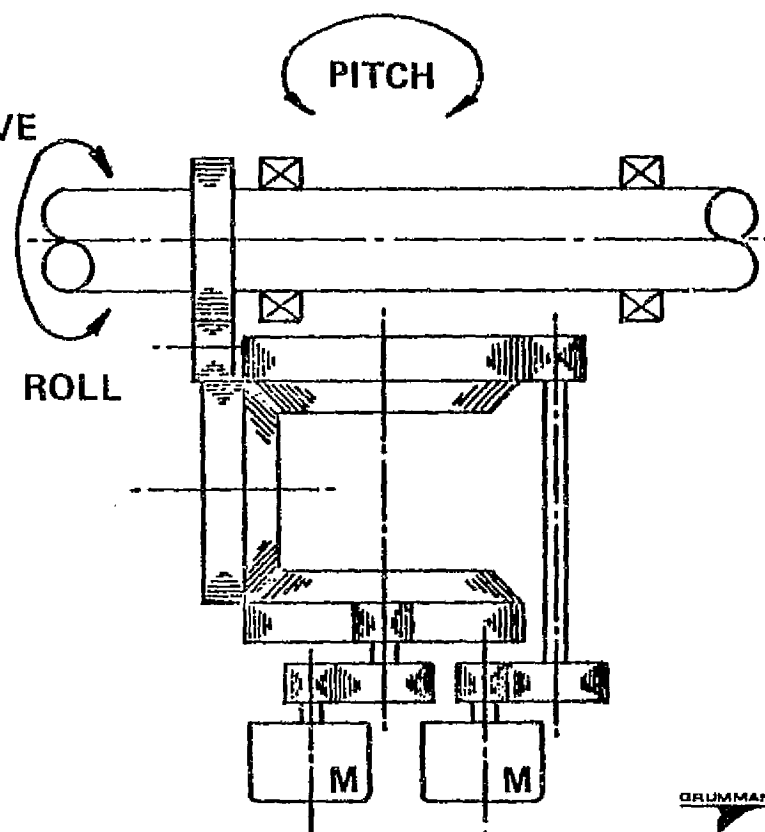
- Lower perceived inertias
- Lower perceived friction
- Better motor duty cycle
- Fewer moving parts.

DESIGN FEATURES

SHOULDER PITCH AND ROLL DRIVE (MASTER AND SLAVE)

TWO MOTIONS LINKED BY DIFFERENTIAL:

- MORE COMPACT DRIVE, LOWER INERTIA
- LOWER GEAR RATIOS
- TWO STATIONARY MOTORS
- SUITABLE MOUNTING BOX FOR YAW DRIVE



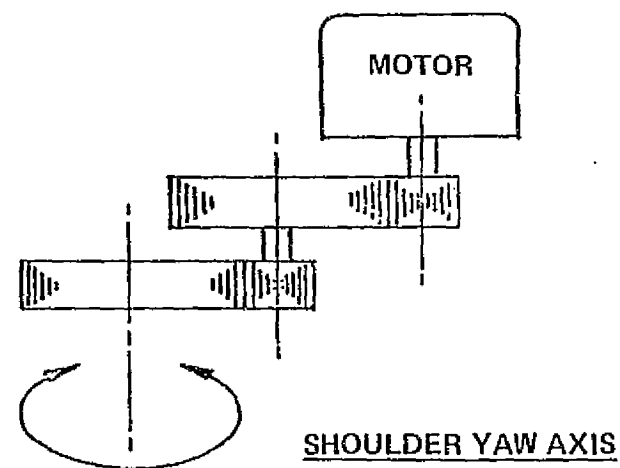
DETAIL DESIGN FEATURES (CONTD)

Both shoulder yaw and elbow pitch drives use simple two-stage spur gear boxes. Gear ratios are quite low (80 for shoulder-yaw, 38 for elbow pitch). This is according to the state-of-the-art of BFR manipulator design.

DESIGN FEATURES (CONTD)

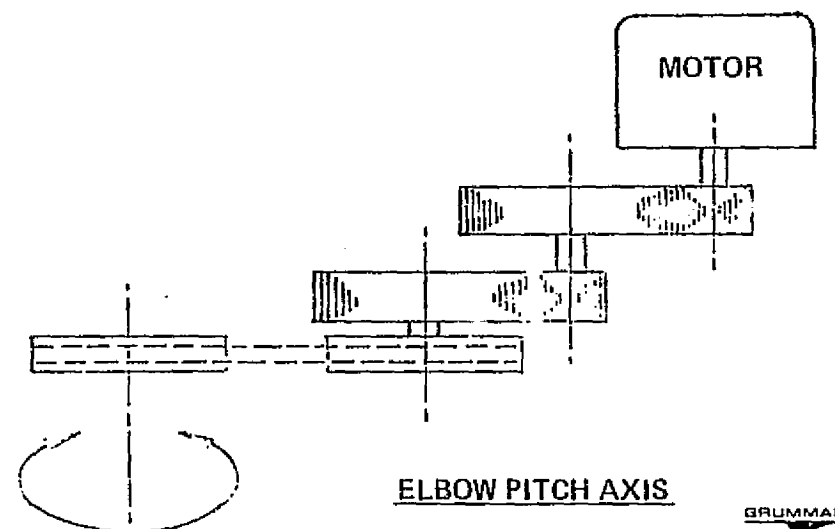
SHOULDER YAW DRIVE

- SIMPLE TWO-STAGE SPUR GEAR REDUCTION
- CAN BE USED IN BFR MODE
- NORMALLY RATE CONTROLLED FROM SEPARATE CONTROLLER



ELBOW PITCH DRIVE

- SIMPLE TWO-STAGE SPUR GEAR REDUCTION
- DRIVE LOCATED BEHIND SHOULDER PITCH PIVOT
- ELBOW CONNECTED TO DRIVE BY CABLE BELT



GRUMMAN

DETAIL DESIGN FEATURES (CONTD)

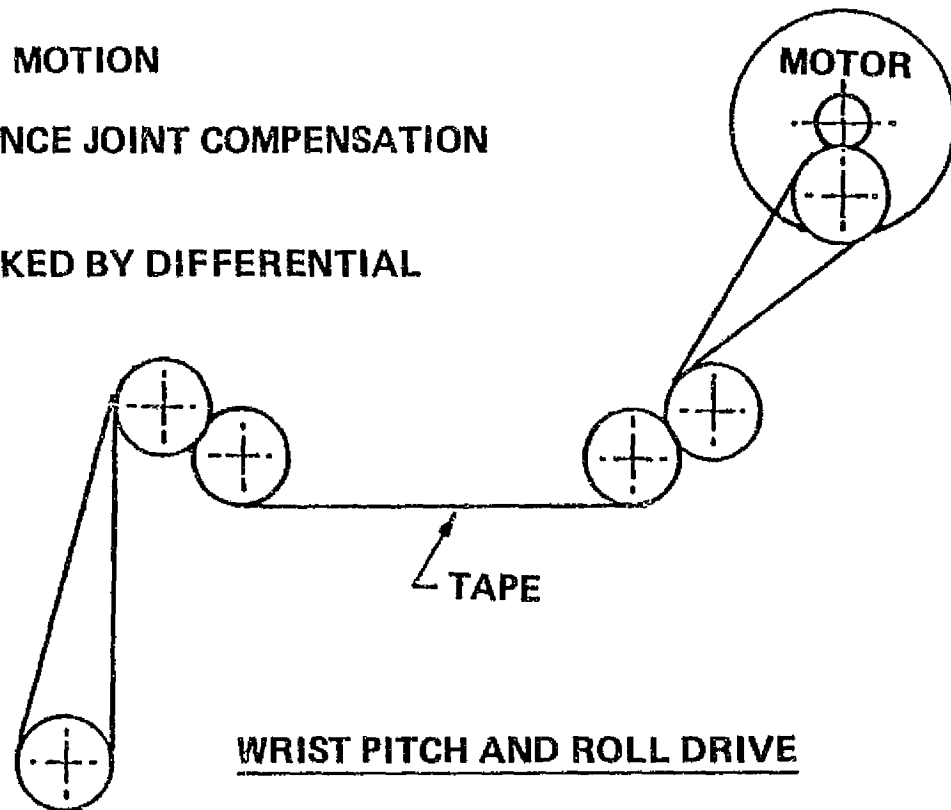
Despite the requirement to do simulation in one g environment, the counterbalance system used, allows one to compensate for gravitational forces on the manipulator arms and still preserve dynamic equivalence to flight hardware.

This is achieved by tendon driving all wrist motions. The joint compensation of the tendons is theoretically exact and unique.

DESIGN FEATURES (CONTD)

WRIST MOTIONS

- MOTOR LOCATED ON COUNTERBALANCE BLOCK
- WRIST DRIVEN BY TENDON TAPES
- TWO TAPES USED FOR EACH MOTION
- ELBOW AND COUNTERBALANCE JOINT COMPENSATION EXACT
- WRIST PITCH AND ROLL LINKED BY DIFFERENTIAL IN WRIST



GRUMMAN

LABORATORY MANIPULATOR PERFORMANCE PARAMETERS

The important operating parameters are well within acceptable limits for the state-of-the-art BFR manipulator system. Flight hardware should follow these parameters quite closely. This is particularly important for inertia parameters.

LABORATORY MANIPULATOR PERFORMANCE PARAMETERS

| | UNITS | SHOULDER | | | ELBOW PITCH | UNITS | WRIST | | | TONG |
|-------------------------------|---------|----------|------|-----|----------------|---------------------|-------|------|-----|-------|
| | | PITCH | ROLL | YAW | | | PITCH | ROLL | YAW | |
| TIP FORCE | LB | 15 | 15 | 15 | 15 | LB | 15 | 15 | 15 | 30 LB |
| NO LOAD SPEED | IN./SEC | 30 | 30 | 30 | 30 | IN./SEC | 30 | 30 | 30 | --- |
| MOMENT ARM | IN. | 80 | 44 | 80 | 44 | IN. | 5 | 4 | 6 | --- |
| FRICTION (MASTER-SLAVE) | OZ | 4 | 4 | 4 | 4 | IN./OZ | 40 | 40 | 40 | --- |
| SENSITIVITY (SLAVE-MASTER) | OZ | 5 | 5 | 5 | 5 | IN./OZ | 50 | 50 | 50 | --- |
| INERTIA FORCES* 0.3G | LB | 6.5 | 6.5 | 7.0 | 6.5 | LB-IN. ² | 110 | 80 | 160 | 30 LB |
| INERTIA FORCES* TO 2G | LB | 4.5 | 4.5 | 5.0 | 4.5 | LB-IN. ² | 65 | 55 | 100 | 20 LB |

* INERTIA FORCES GIVEN FOR MAX VELOCITY POSITION

